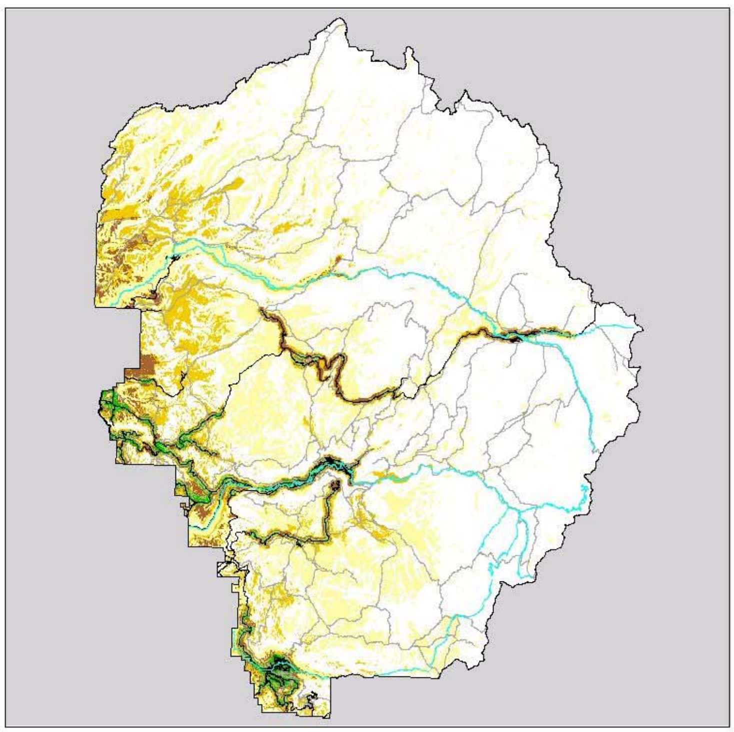
The Design of Sampling Protocols for an Inventory of Alien Plant Species in Burned and Riparian Areas in Yosemite National Park, California

Final Report Submitted to the National Park Service



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INTRODUCTION

The Vail Agenda's strategic plan for the National Park Service (NPS) in 1991 emphasized the importance of good quality information on natural resources in the national park system being readily available to park managers. In order to fulfill the NPS mission of conserving parks unimpaired (Fancy 2001), revised NPS policy and recent legislation (NPS Omnibus Management Act of 1998) require that park managers now know the condition of natural resources under their stewardship. This entails monitoring those resources to detect long-term trends. The National Park Service Inventory & Monitoring Program (NPSIMP) was established in the 1990's, with the following goals:

1. Conduct baseline inventories of biological and geophysical resources in all natural resource parks.
2. Develop long-term monitoring programs of status and trends of the parks resources
3. Integrate technological developments, such as Geographic Information Systems, into resource management programs supporting decisions made on resource management.
4. Integrate resource inventory and monitoring programs with other park programs, such as planning, operations and maintenance, visitor use, and interpretation.
5. Cooperate with other agencies and organizations involved in conservation and resource protection. This involves cost and information sharing as well as achieving common goals.

The program was divided into two phases. The first phase, which began in 1991, had two goals: (1) completing inventories in most parks; and, (2) developing, implementing, and evaluating prototype monitoring programs in a smaller number of selected parks. The goal of Phase II would be wide scale implementation of monitoring throughout the NPS system.

Inventorying of natural resources was implemented in Yosemite National Park in 1989 (P. Moore, USGS-BRD, pers. comm.), but implementation of the NPSIMP began in 1991. Earlier inventory work by NPS was park specific, whereas the NPSIMP was focused on meeting nationally defined goals.

Yosemite is one of the most visited parks in the United States. Known throughout the world for its scenic attractions, it also has many ecological values. The size and elevation range of the park result in a variety of vegetation communities within its boundaries. The flora and fauna within the park is relatively intact, and most of the natural processes characteristic of the ecosystems within the Sierra Nevada mountains continue to occur (albeit with different properties than prior to arrival of Europeans over 200 years ago; e.g. fire regimes). Management actions by the National Park Service are focused on minimizing human impacts while still providing for public visitation. Examples of these management actions include confinement of development in the park to several designated areas, restrictions on livestock and domestic animals along park trails, and restrictions or prohibition of land management activities known to have detrimental effects on ecosystems in California (e.g. cattle grazing practices typical of the Central Valley).

Despite these policies, human activities still have appreciable impacts on the park, and present a number of management challenges to NPS staff. One issue that has both immediate and long-term implications for management actions in Yosemite is the invasion of alien species. The effect of invasion by alien species into natural systems is generally regarded as one of the most critical issues confronting conservation science (Drake et al. 1989, Simberloff et al. 1997, Mack et al. 2000). Concern over the impacts of invasive species has moved progressively from the local (Minnich 1980, Braithwaite et al. 1989) to regional (Macdonald et al. 1986, Naylor 1996) and even global scales (Vitousek et al. 1996, Mack and D'Antonio 1998, Mack et al. 2000). While biological invasions are a natural ecological process, the worldwide rate and extent of invasions and the number of species that are now considered invasive is probably unprecedented (Di Castri 1989). The Sierra Nevada Ecosystem Project report identified three areas in the Sierra Nevada that are "high-impact" areas for alien plant invasions. These include valley grasslands and foothill oak woodland, riparian zones, and the eastern slope (Schwartz et al. 1996).

It is the policy of the National Park Service to allow natural disturbances such as fires, flooding, and erosion to occur within designated areas of many national parks (USDI-NPS 2001). However, many invasive species are known to exploit the disturbed conditions that result from these natural processes (Rejmanek 1989, Hobbs 1991, Mack and D'Antonio 1998). Consequently, park staff is concerned that areas of natural disturbance could be invaded by alien species. In particular, when disturbance occurs in remote areas of the park there is a distinct possibility that invasive alien plants could go undetected and proliferate. Ironically, the implementation of management activities, such as prescribed fire, and the associated positive effects to ecosystem properties could be compromised by invasions of alien plants (Stephenson et al. 1991, Stephenson 1999, Keeley 2001). Also, disturbed sites in close proximity to human activities could be susceptible to high rates of invasion as a result of propagules from colonizing sources, such as campgrounds or trails (Macdonald et al. 1988).

In 1996, the Biological Resources Division of the United States Geologic Survey (BRD) began surveys to determine distribution and abundance patterns of alien plant species in Sequoia National Park. Surveys of alien plants in Yosemite were conducted in areas of anthropogenic disturbance (e.g. campgrounds, corrals, roads and trails) in 1998 and 1999 (Gerlach et al. 2001). A total of 130 alien plant species were recorded in the surveys, sixteen of which were included on the California Exotic Pest Plant Councils list of alien species of greatest concern in wildlands of the state (CALEPPC 1996). These surveys indicated that alien plants occurred throughout the park, but most species were concentrated at lower elevations.

At present, there is no inventory or monitoring program for alien plant species in areas of natural disturbance within Yosemite National Park. The most common types of "pulse" natural disturbances (sensu Bender et al. 1984) in Yosemite and throughout much of the Sierra Nevada are wildfire and flooding. Because these disturbances not only occur naturally but also as a result of NPS management activities (e.g. prescribed fire), understanding the relationship between disturbance and susceptibility to invasion by alien plant species in Yosemite is critical. Consequently, the development of an inventory and monitoring program of invasive alien plant species in areas of natural disturbance is a high priority for BRD and NPS scientists and NPS resource management staff.

This report describes the procedures used for the development of a sampling protocol for inventorying alien plant species in wildfire and riparian areas in Yosemite National Park. The inventory has two purposes; first, to provide data for an analysis of general patterns of distribution and abundance of alien species in wildfire and riparian areas; and second, to create a baseline dataset to compare future surveys with. It will also be the initial step in developing a formal monitoring protocol for alien species in wildfire and riparian areas in the park.

RATIONALE AND APPROACH

The goal of the study was to develop sampling protocols that would maximize the number of species likely to be found in an inventory of alien plants in burned and riparian areas in Yosemite National Park. Although the structure of inventory and monitoring programs can grade into each other, there is an important distinction. The success of a monitoring program is dependent upon statistical power to detect significant trends over time and evaluate relationships between variables. In contrast, the success of an ecological inventory depends upon whether an entire census of a community can be conducted, or, if a census is not feasible, survey protocols can be implemented that are large enough in scale and representative enough to provide meaningful estimates of distribution and abundance patterns. Recording of common species is not an issue in surveys because of their obvious abundance, but sampling intensity must be high enough that less abundant species are included. In addition, sampling must also be efficient and maximize return for effort - focusing on areas where invasive plants are most likely to occur versus a “shotgun” approach. In short, sampling protocols need to be comprehensive, but also targeted and efficient.

Inventory programs can, and often are, implemented without any data to base development of sampling protocols on. However, the effectiveness of initial surveys can be substantially improved if development of protocols is based on previously collected data. For Yosemite, three different sources of data on distribution and abundance of alien plants in the park were available. These three sources were:

1. A vegetation inventory and mapping program (Natural Resources Inventory program) conducted from 1989 – 1993 (NRI plots; N = 362 0.1 ha plots).
2. A vegetation community mapping program conducted by The Nature Conservancy in 1998 and 1999 (TNC plots; N = 343 plots). Plot size varied by plant community

type and shape varied within communities, although plot size within communities was constant.

3. A species list from monitoring plots established in burned areas in Yosemite and sampled over the last 10 years (FMH plots).

The most important aspects of a sampling design for inventory programs are the number of plots, their shape, and where they are located. The three data sets provided a good foundation for development of an effective sampling design. We felt a useful approach would be to proceed in five coordinated steps. The first step would be to evaluate the different data sets to identify inherent strengths and weaknesses in each one that could either be informative or misleading.

The second step would be an analysis to determine general patterns of distribution and abundance for alien plant species. Analyzing species distribution and abundance patterns would help estimate the number of plots needed to sample within certain levels of accuracy (e.g. mean number of alien species/plot) for a given level of precision, as well as helping determine plot size and shape. They would also be useful for determining the cumulative number of alien species likely to occur in areas of natural disturbance in the park.

The third step would be analyzing associations among the alien species and relationships between alien species and different biological and physical variables. Analysis of these relationships would aid in determining what plant community and habitat types alien species were most likely to occur in. They could also be useful for determining what physiographic features of the environment were related to different species or groups of species.

The next step would be to use the biological and physical variables that were correlated with species distribution patterns as inputs into Geographic Information System (GIS) models that predict areas of likely alien species occurrence. The GIS models would extrapolate landscape features that were correlated with the distribution and abundance patterns of alien species, then map potential distribution patterns of individual alien species or groups of alien species throughout the park.

The final step would be to select plot locations. Based on the predicted distribution of alien species occurrence and the relationship of key physiographic variables with their occurrence, random locations would be generated in the GIS for the establishment of plots.

Based on this approach, we set seven primary objectives for the study:

1. Evaluate the suitability of the data in the different databases for different types of analyses.
2. Analyze existing data on species composition, distribution, and abundance of alien vascular plants in burned and riparian areas.

3. Make estimates of the number of plots needed to inventory alien plants in burned and riparian areas.
4. Make a determination of the size of plot needed to inventory alien plants in burned and riparian areas.
5. Analyze GIS data to relate landscape features correlated with the distribution and abundance patterns of alien species.
6. Develop predictive models for identifying areas of alien species occurrence based on key landscape features.
7. Develop a sampling protocol for estimating abundance of alien plants in burned and riparian areas.
8. Identify plot locations for implementation of the inventory by the NPS and BRD.

We also set three secondary objectives:

1. Develop a database for storing the inventory data collected in the field.
2. Outline proposed steps, procedures, and statistical tests for analyzing the data collected in the inventory.
3. Provide a literature review on the interaction between alien species and natural disturbance events (fire, flooding) pertinent to Mediterranean climates in California.

This report is organized in two sections. The first describes the community scale analyses that were conducted on the TNC and NRI plot data, while the second section explains the GIS methodology and predictive model approach. A description of the technical approach has been given in some detail so that the procedures can be repeated if necessary in the future. Although the activities are not in chronological order, for example analyses of plot data incorporated results from the GIS, they have been kept as separate intact entities for conceptual clarity.

SECTION I: COMMUNITY SCALE ANALYSES OF PLOT DATA

A. METHODS

A.1. Compilation and Evaluation of Data Sets

All three data sets were inspected for consistency in species identification and completeness. Review of the species data in the FMH data set indicated that there were numerous cases of doubtful species identification. Assigning consistent acronyms to the species appeared to have been done haphazardly in some cases, and there were too many species listed as "unknowns" for us to feel confident in the data. We had been cautioned that this data was of dubious quality (K. Paintner, NPS, pers comm.), which clearly was the case. Therefore, the FMH data set was not used in any part of this study.

Taxa in the NRI and TNC data sets that were not positively identified to species (e.g. just to genus) were omitted from all analyses. This resulted in omission of < 0.5% of the records in the two databases. All species retained for the analyses were coded as being native or alien.

Since cover data had been collected with a similar technique in the TNC and NRI studies we considered combining the two data sets. However, there was the potential for serious problems because of differences in size and shape of plots between the two studies. The NRI study used circular 0.1 ha plots (17.84 m radius), but the TNC study had used several different plot sizes and three plot shapes. These differences could result in patterns that were artifacts of the sampling design and not any underlying ecological processes. This could then lead to misinterpretations of patterns of species richness, diversity, and composition. It also presented potential problems within the TNC data set because of the differences in plot size and shape between the different community types. What might appear to be differences in distribution and abundance patterns of alien species between communities could, again, be the result of different plot configurations.

We used analysis of covariance (ANCOVA) to test for differences in species richness between square and rectangular shaped plots of different size in the TNC data set. The plot sizes were 100 m^2, 400 m^2, and 1000 m^2. Differences in species composition between square and rectangular shaped plots of different size in the TNC data set were tested by calculating a bootstrapped Morisita-Horn index for each of the six different size/shape categories. Fifty bootstrap samples were taken for all species and another 50 for just alien species within each category. A similar procedure was used to compare species composition between the NRI and TNC data sets, but the comparisons simplified to just two - TNC vs. NRI. The program EstimateS (Colwell 1997) was used to calculate the bootstrapped Morisita-Horn indices.

Chi-squared tests were used to determine if the proportion of plots in different vegetation formations was similar between the TNC and NRI data sets. The geographic (UTM) coordinates of each plot were imported into the GIS and plots were assigned to vegetation formation. Vegetation formations were derived from maps based on surveys originally done in 1937. More recent classifications of vegetation types in Yosemite based on the NRI and TNC data sets have been completed. Formations and alliances from these classifications were drawn on to the original maps. The formation rather than alliance level of classification was used because an insufficient number of plots for analysis would have occurred by using the alliances.

A.2. Analysis of Species Composition, Distribution, and Abundance of Alien Vascular Plants in Burned and Riparian Areas

Data for the NRI and TNC plots were summarized in several ways. Descriptive statistics were calculated for the total number of alien species, the number of plots they occurred in, their mean cover values, and their total cover value in each plot.

A negative binomial distribution was fit to the distribution of the number of alien species in the NRI and TNC data sets. This enabled us to determine the degree of aggregation of the species and to estimate the number of samples needed to achieve a confidence limit between 5-40% of the mean number of alien species/plot with 90% and 95% confidence intervals. The exponent of the negative binomial distribution was used to determine the degree of clumping.

Bootstrapping procedures (Manly 1991) were used to determine the approximate number of plots where the mean number of alien species/plot and mean cover values for those species stabilized. One hundred bootstrap samples were run for each of 18 different sample sizes for the NRI data; 20, 40, 60, 80, 100, 120, 140, 160, 180, 200, 220, 240, 260, 280, 300, 320, 340, and 350 plots. One hundred bootstrap samples were run for each of 12 different sample sizes for the TNC data; 20, 40, 60, 80, 100, 120, 140, 160, 180, 200, 220, and 235 plots. The mean and standard error were calculated for each sample size and the curves plotted.

Bootstrapping techniques were also used to produce species accumulation curves of the total number of alien species observed (SOBS) and the estimated number of alien species expected to occur (Incidence-based Coverage Estimator; ICE) in samples ranging from 1-356 plots (NRI data) and 1-236 plots (TNC data). ICE is a modification of procedures used for estimating population size of animals, and uses the presence-absence (incidence) of rare species in a series of samples to estimate the probability of the number of species not found in a series of samples (Colwell and Coddington 1994, Lee 1994). This estimate is added to the number of species recorded in samples and the total used as a measure of the number of species. The program EstimateS (Colwell 1997) was used to calculate SOBS and ICE. Fifty bootstrap samples were taken for a given number of plots in the NRI and TNC data sets.

Finally, bootstrapping was used to evaluate the relative effectiveness of different plot sizes for detecting alien species. Species accumulation curves were calculated for the mean cumulative number of alien species recorded in plots varying in size from 0.1-1.0 ha. Fifty bootstrap samples were taken for each plot size for both the TNC and NRI data sets. Because of the different plot sizes in the TNC study, a “mean” plot size was calculated from 1000 bootstrap samples of the TNC plots. The "mean plot size" estimate of the TNC data was 0.48 ha. This estimate was rounded to 0.50 ha.

A.3. General Relationships of Alien Species with Biological and Physiographic Variables

The total number of alien species, percentage of alien species, and the absolute and relative cover (%) of alien species were calculated for all plots in the NRI and TNC data sets. Plots were also coded as having alien species present or not present, regardless of the number of aliens when present.

Since a single number fails to adequately describe diversity patterns, four indices of species diversity were calculated for each plot in the NRI data set, (Magurran 1988). These included S, N_1, and N_2, which are measures of richness and heterogeneity and are progressively less sensitive to the contribution of rare species. S was the total number of species in a 0.1 ha plot, N_1 is $\exp^{H'}$, where H' is Shannon's diversity index, and N_2 is 1/C where C=Simpson's index of concentration (Hill 1973). Molinari's index (G) was used to calculate evenness, because it has been found to be the index of evenness that is least affected by the influence of one dominant species (Molinari 1989).

Values for 22 physiographic variables were determined for each plot in the NRI and TNC data sets. These included elevation, slope, aspect (calculated as degrees deviance from true north), the percent cover of trees, shrubs, and herbaceous species, the number of species of trees, shrubs, and herbaceous species, the percentage of stone, silt, clay, sand, loam, gravel, boulder and cobble in the soil, size of burn (if a plot occurred in a burned area), the perimeter of the burn, the ratio of edge to area of the burn, the number of years since the last burn and the distance (m) from a stream, road, trail, or campground. Data for some of these variables were collected in the field, but conducting a spatial join between the plot locations and the physiographic layers in the GIS generated others.

Forward stepping logistic regression was used to select the best sub-set of the 22 structural variables that predicted the occurrence (presence/absence) of alien species in the NRI (N=356) and TNC plots (N=236). Separate analyses were run for each data set. Following the logistic regression, linear regression was used to analyze the correlation of species richness (absolute and percent of all species) and cover (absolute and relative) of alien species with physiographic variables that had a significant correlation with the presence of alien species in a plot. Logistic and linear regression were used to analyze the correlation of presence/absence and abundance of alien species with the four indices of diversity for the NRI data set.

Chi-square analysis was used to test if the proportion of alien species in different vegetation formations was equal to the proportional occurrence of the vegetation formations in the park. The vegetation formations were weighted by their proportional occurrence within the park. Separate analyses were conducted for the NRI and TNC data sets.

Analysis of variance (ANOVA) was used to test for differences in the number and proportion of alien species and absolute and relative cover of alien species between vegetation formations. ANOVA was also used to test for differences in the number and proportion of alien species and absolute and relative cover of alien species between burned and unburned areas. Residuals were first analyzed to see if the dependent variables met the assumptions of ANOVA. The data were skewed for all variables, so the number and percentage of alien species were logarithmically transformed (log+1) and the absolute and relative cover values were arcsine transformed. The transformations improved the skewness but the large differences in sample size between vegetation formations led to inequality of variances. Therefore, ANOVA's for the vegetation formations used separate variance calculations. We expected to find a higher number of alien species in some vegetation formations than others (e.g. meadows and grasslands), so if the overall test was significant we used planned comparisons to test for differences between particular vegetation formations (Day and Quinn 1989). Separate analyses were conducted for the NRI and TNC data sets.

A.4. Species Associations

Species associations were analyzed with Two-Way Indicator Species Analysis (TWINSPAN) (Gauch 1982). TWINSPAN is an iterative, polythetic, divisive classification method that does an initial ordination of sites and species (reciprocal averaging; ter Braak 1995), then divides groups of maximally dissimilar species and again re-ordinates the species and plots. This procedure continues until clusters can no longer be divided into separate groups.

We had originally intended to conduct three different analyses for both the NRI and TNC data sets. In the first analysis all species in the plots would be included, in the second only alien species would be used, and in the third only native species were to be included. We believed that this would allow us to determine the relative importance of alien species to associations in different community types. But because of the large number of plots in both data sets without alien species this approach would have not been particularly informative. Therefore, the analysis was restricted to only those plots with at least one alien species. The minimum size used for dividing groups was five, and the maximum number of divisions was restricted to six. The program PC-ORD was used to run the TWINSPAN (McCune and Mefford 1999).

A.5. Correlation of Abundance of Alien Species with Environmental Gradients

Canonical Correspondence Analysis (CCA) was used to ordinate species and plots along gradients of topography (slope, aspect, elevation), vegetation structure (percent cover of trees, shrubs, and herbaceous species, the number of species of trees, shrubs, and herbaceous species), soil (% stone, silt, clay, sand, loam, gravel, boulder and cobble), and burn characteristics (burn size, burn perimeter, ratio of edge to area, and years since most recent burn) (ter Braak 1995). The NRI and TNC data sets were initially analyzed separately, but an analysis that combined plots from both data sets where alien species occurred was done as well.

Three separate analyses were conducted for both data sets. All species (native and non-native) that occurred in ≥ 3 plots in the NRI data set were included in the first analysis (N=189 species and 356 plots), while all 765 species that occurred in the 236 plots in the TNC data set were retained. This was done for practical purposes. The number of records in the NRI data set exceeded the capabilities of the computer program. CCA is not sensitive to the occurrence of rare species, so restricting the number of species in the NRI data set to 189 had negligible effect on the ordination.

In the second analysis we included only alien species (N=18 species and 36 plots for the NRI data, and 41 species and 57 plots for the TNC data) and the environmental gradients that had significant effects on the ordination from the first analysis. In the third analysis we derived gradients based solely on patterns of distribution and abundance for alien species. The rationale for taking this approach was to determine if alien species were responding in a similar way to gradients that shaped overall species distribution patterns. If they were not, or if other variables had a stronger correlation with distribution patterns of aliens, then we could incorporate the variables with the most predictive power into the GIS analysis.

Forward stepping multiple regression was used to select the variables that contributed significantly to the ordination, and permutation tests were used to test the significance of the first ordination axis and the overall ordination (ter Braak 1995). A total of 199 permutations were used to calculate significance levels. Program CANOCO 4 was used to perform the CCA's.

A.6. Alien Species and Riparian Areas

Because we were interested in patterns of alien species distribution and abundance in riparian areas as well as burned areas we tried to determine if there were species that occurred only in areas that, even in the broadest sense, could be considered riparian. A preliminary analysis indicated that there were no species we could reliably assign as strictly occurring in riparian areas, or that there were any patterns in the NRI or TNC data sets that indicated the abundance or distribution of alien species were related to riparian areas. There was no correlation with presence/absence of alien species and the distance from a watercourse (logistic regression; $p=0.59$), or between distance from stream and the number or cover of alien species (linear regression; $p>0.691$). There were only two species that occurred only in areas that could even remotely be considered riparian. These were *Myosotis discolor* and *Poa annua*, and each species occurred in one plot each. Because of this we focused all analyses on patterns of alien species in burned and unburned areas. We will return to the issue of alien species in riparian areas in the Discussion and Recommendations sections of the report.

A.7. Literature Review

A search was made of the computerized databases BIOSIS 1993 – present, BIOSIS 1983 – 1993, Web of Science, and the E.V. Komarek Tall Timbers Research Station fire literature database. Keywords used in the search included different combinations of fire, wildfire, prescribed fire, controlled burns, experimental burns, riparian, flooded, alien species, exotic species, invasive species, and non-native species. In addition, a manual search was made by cross-referencing citations in older (pre-1983) papers. References were primarily limited to Mediterranean-type ecosystems, although some references from other ecosystems were included if they were considered pertinent. In some cases, species specific references were included for alien species found to be common in the plots. All references were entered into Endnote software (version 4.0.1).

B. RESULTS

Of the 362 0.1 ha plots in the NRI data set, six were in areas that were almost entirely rock slab. These six plots were excluded from further analysis because they had no data on native or alien species.

The ANCOVA of the TNC data indicated plot size and shape confounded differences in patterns of species diversity and composition between communities. There was a significant increase in the total number of species and the number of native species as plot size data increased (Figure 1). The number of species nearly doubled between the 100 m^2 and 1000 m^2 plots. Rectangular plots had significantly more native and total number of species than square plots for all plot sizes (Figure 1). There was no significant relationship between plot size or shape and the number of alien species (Figure 1).

Species similarity was generally low between the different plot sizes and shapes within the TNC data set (Table 1). There were no distinct patterns in similarity for either plot shape and plot size for native, alien, or the total number of species. Overall mean species similarity for native species and the total number of species was 0.35. Mean species similarity for alien species was 0.30. The highest similarity was 0.64 and the lowest 0.07.

Similarity for the total number of alien species between the NRI and TNC data sets was somewhat higher than within the TNC data set (Table 2). Morisita-Horn similarity index values between the two data sets ranged from 0.49 – 0.69 within burned and unburned conditions and for the total number of alien species. Similarity in species composition between burned and unburned conditions within each data set was quite high (Table 2). Morisita-Horn values were 0.86 between burned and unburned conditions for the NRI data and 0.90 for the TNC data. There was a significant difference in the proportion of plots in different vegetation formations between the two data sets (X^2 = 42.2, df=9, p<0.0001). The main difference was in the number of plots in grassland and meadow areas. Approximately 8% of the NRI plots were in the grassland and meadow formation, compared to 22.5% of the TNC plots (Table 4).

Because of the confounding of diversity and composition patterns between vegetation community types with plot sizes and shapes in the TNC data set, we restricted our analyses involving general patterns of diversity and relationships between alien and native species to the NRI data set. We decided that analyses involving alien species within the TNC data set were justified, but interpretations would have to be made cautiously. We determined that our best strategy would be to first look for consistency in results between the two data sets without combining them. Ordination and analyses of species association (e.g. TWINSPAN, CCA) depend primarily on distribution and abundance patterns between species, and/or correlation with environmental variables. They are not as sensitive to differences in diversity as are general community-level statistics such as diversity and similarity indices. Therefore, we decided to combine the TNC and NRI data on alien species for the ordination and species association analyses. We felt this approach could provide data useful for computer modeling, but we also recognized that the disproportionate allocation of plots between the grassland and meadow formation made this approach tenuous. At best, we knew interpretations of the combined data would have to be made very carefully, and that there was a good chance the results would not be useful at all.

B.1. Distribution and Abundance of Alien Species

A total of 18 alien species were recorded in the 356 NRI plots and 41 in the 236 TNC plots, with a total of 46 between the two data sets (Table 3). This represented 2.7% of the total number of species recorded in the NRI plots and 5.4% in the TNC data set. Twenty-one of the alien species were grasses and the rest forbs. *Bromus tectorum*, *Vulpia myuros*, and *Poa pratensis* were the most widely distributed and abundant species. Collectively, these three species had mean cover values of < 6%.

Alien species occurred in 10.1% of the NRI plots (N=36; Table 3). The mean number of alien species/plot in the NRI data set was 0.17 (95% confidence intervals 0.10-0.24). Mean alien cover in the NRI data set was 0.22% (95% confidence intervals 0.12-0.32). Burned plots comprised 12.6% of the total NRI plots, but of these only 5 had alien species (1.4%).

Alien species occurred in 23.7% of the TNC plots (N=56; Table 3). The mean number of alien species/plot in the TNC data set was 0.69 (95% confidence intervals 0.47-0.91). Mean alien cover was 2.8% (95% confidence interval 1.4-4.2). In contrast with the NRI data set, 26.3% of the TNC plots occurred in burned areas (N=62). Thirty of these burned plots had alien species present (48.4%).

The distribution of alien species in the NRI plots was highly aggregated (negative binomial k = 0.114, P = 0.54 under H_o of distribution not significantly different from negative binomial). Ten of the 18 alien species in the NRI data set occurred in only one plot, and none of the species had mean cover values > 3.0% (Figure 2). The distribution of alien species in the TNC plots was also highly aggregated (negative binomial k =

0.168, P = 0.17). Nine of the 41 alien species in the TNC data set occurred in only one plot, and > 70% of the species had mean cover values < 3.0% (Figure 2).

Alien species in the NRI data set occurred most frequently in subalpine conifer forest and upper and lower montane conifer forest, but this was not disproportionate relative to the area of the formations ($X^2 = 3.311$, df=8, p=0.913) (Table 4). There was no significant difference in species richness or cover of alien species between the vegetation formations (p>0.098; Figure 3). There was no significant difference in species richness or cover of alien species between burned and unburned plots (Figure 4). There was no correlation of the occurrence or abundance of alien species with any of the diversity indices (p>0.46).

In contrast with the NRI data, alien species in the TNC data set occurred more frequently than expected in grassland/meadow formations and lower montane conifer forest formations. They occurred less frequently than expected in subalpine conifer forest formations ($X^2 = 10.50$, df=4, p=0.030) (Table 4). Sample sizes were too low in woodland and chaparral formations for statistical tests. Species richness and absolute and relative cover of alien species were significantly lower in subalpine and upper montane conifer forests than in other vegetation formations (p<0.05; Figure 5). Species richness and cover of alien species were significantly higher in burned plots than unburned plots (p<0.048; Figure 6). However, mean absolute and relative cover in burned areas was < 20%, and there were on average < 4 alien species/burned plot (Figure 6).

B.2. Correlation of Alien Species Distribution and Abundance with Biological and Physiographic Variables

The incidence of alien species in the NRI data set had significant odds ratios for six variables; elevation, the number of tree, shrub, and herbaceous species, and the percentage of sand and loam in the soil (Table 5). Plots with alien species tended to occur most frequently at relatively low to mid-elevations (3,500 – 10,000 feet; median = 5,000 feet) in sandy areas with other herbaceous species. The classification success of plots with alien species was only 53%, but the classification success of plots without alien species was 95%. The overall classification success was 90.4%. McFadden's $rho^2 = 0.481$ (p<0.0001), indicating the six variables accounted for a significant proportion of the variation in the incidence of alien species.

The incidence of alien species in the TNC data set had significant odds ratios for four variables; elevation, slope, the number of herbaceous species, and the percentage of cobble in the soil (Table 5). Plots with alien species tended to occur most frequently at relatively low to mid-elevations in flat areas with other herbaceous species. The classification success of plots with alien species was 65%, and the classification success of plots without alien species was 89%. The overall classification success was 83.5%. McFadden's $rho^2 = 0.515$ (p<0.0001), indicating the four variables accounted for a significant proportion of the variation in the incidence of alien species.

Multiple linear regression analysis indicated that elevation and the number of herbaceous species were significantly correlated with alien species richness for the NRI data (Table 6). There was no significant relationship between cover of alien species and any of the variables for the NRI data. Species richness and cover of alien species in the TNC data set had a significant correlation with elevation and herbaceous cover (Table 6).

B.3. Species Associations and Correlation of Environmental Variables with Alien Species Assemblages

TWINSPAN of the NRI data indicated that there were three major groupings of alien species (Figure 7). The first group was characterized by *Bromus tectorum* and *Vulpia myuros hirsuta*, the second grouping by *Poa pratensis* and, to a lesser degree, *Holcus lanatus*, and the third by *Rumex acetosella* and *Cirsium vulgare*. TWINSPAN of the TNC data indicated that there were five major groups (Figure 8), and that three of these were relatively similar to the NRI groups. The two largest were characterized by *Bromus tectorum* and *Vulpia myuros* (group 1) and *Poa pratensis* and *Cirsium vulgare*, (group 2). The third group was characterized by *Holcus lanatus*, and the fourth by the *Rumex acetosella* and *Phalaris aquatica*. The fifth group consisted mainly of relatively uncommon species, such as *Bromus hordeaceous* and *Phleum pratense* (Figure 8). This fifth group had no clear relationships with the other groups.

Not surprisingly, the major species associations in the TWINSPAN of the combined NRI/TNC data sets were consistent with the associations in the NRI and TNC analyses (Figure 9). The clearest associations were for a *Bromus tectorum*/*Vulpia myuros* group (group 1), a *Poa pratensis/Rumex acetosella*/*Cirsium vulgare* group (group 2), and a group of species dominated by *Holcus lanatus* (group 3). Two other groups of relatively uncommon species also occurred, but similar to the TNC analysis they had no clear relationships with the other three groups (Figure 9).

The variables that had significant correlation with patterns of species distribution and abundance in the NRI plots are given in Table 7A. The three major gradients in the CCA for the NRI plots where the most common species (native and non-native) were included explained > 72% of the variation in the species data (Table 8). Both the first and overall ordination axes were significant (p=0.005). When these variables were related to distribution and abundance patterns of just alien species neither the first axis (p=0.175) or the overall ordination (p=0.08) was significant (Table 8). The variables that did have a significant correlation with alien species explained > 80% of the variation in abundance (Figure 10). This resulted in both the first axis (p=0.01) and the overall ordination (p=0.005) being significant (Table 8). The first axis was primarily a gradient from plots where soils had a high proportion of cobble to areas where there was little if any cobble. The second axis was a herbaceous cover gradient and the third axis was an elevation gradient (Figure 10). Aspect was correlated with both the first and second axis, but its effect was relatively small compared to the % cobble and percent herbaceous cover.

The variables that had significant correlation with patterns of species distribution and abundance in the TNC plots are given in Table 7B. The three major gradients in the CCA for the TNC plots where the most common species (native and non-native) were included explained > 61% of the variation in the species data (Table 9). Both the first and overall ordination axes were significant (p=0.005). When these variables were related to distribution and abundance patterns of just alien species both the first axis and the overall ordination were significant (p=0.015; Table 9). This ordination species explained 66.3% of the variation in the distribution and abundance of alien species (Table 9). However, both the first axis (p=0.005) and the overall ordination (p=0.005) were significant when an ordination based just on alien species abundance was performed (Table 9). The first three axes of this ordination explained 88.7% of the variation in cover of alien species, but the third axis could not be interpreted clearly. The first two axes explained > 70% of the variation in cover of alien species. The first axis was a shrub cover and slope gradient, and the second axis was an elevation gradient (Figure 11).

The variables that had significant correlation with patterns of species distribution and abundance of alien species in the combined NRI/TNC plots are given in Table 7C. The first three axes explained 60% of the variation in abundance of alien species (Table 10). Both the first axis (p=0.01) and the overall ordination were significant (p=0.005). The first axis was a slope and herbaceous cover gradient. The second axis was a cobble gradient, and the third axis represented boulder and shrub cover gradients (Figure 12). Elevation had a moderately strong correlation with the second axis, and although burn perimeter was a significant variable in the ordination its explanatory power was low (Figure 12).

The three data sets tended to have similar gradients that abundance of alien species was correlated with. Differences in the relative importance of some of the variables were likely due to the smaller number of alien species and plots with alien species in the NRI data set. The CCA of the combined NRI/TNC data explained less of the variation in distribution and abundance patterns of alien species than the TNC data. Therefore, we gave the most weight to the variables from the TNC ordination as inputs into the GARP analyses.

Synthesizing the results of the logistic and linear regression analyses, the TWINSPAN's, and the CCA's, the variables that appeared likely to have the greatest chance for accurately predicting where different groups of alien species occurred were elevation, slope, and vegetation structure (the relative amounts of shrub and herbaceous cover). Because data are not available in the GIS on the percent cover of different vegetation layers at any given location, vegetation alliance could act as a surrogate for vegetation structure.

B.4. Sample Size and Plot Shape Selection

Estimates of sample effort required for inventorying alien species in burned and unburned areas with different combinations of accuracy and precision are given in Table 11. These estimates were derived for aggregated distributions of species that are representative of a negative binomial distribution, which the alien species in both the NRI and TNC data sets are. These estimates are for a standardized plot size of 0.1 ha, and it is clear that a tremendous number of samples would be needed to obtain acceptable levels of precision.

Bootstrapping simulations of the mean number of alien species/plot and the mean cover of alien species/plot indicated that the mean number of species and mean cover tended to stabilize after 5 to 10 plots in burned areas were sampled (Figure 13). However, the simulations also indicated that approximately 340 unburned plots would have to be sampled to observe the 18 species recorded in the NRI plots (Figure 14). Based on this sampling effort, it was estimated that there were > 35 alien species (ICE), but this was likely a severe underestimate because the curve for ICE did not appear to be reaching an asymptote (Figure 14). In burned plots only six species would be recorded if approximately fifty 0.1 ha plots were sampled (Figure 14), while the curve for ICE indicated there would be >>30 species.

Curves for SOBS and ICE derived from the TNC data are only slightly more optimistic (Figure 15). The ICE curve for all plots begins to reach an asymptote near 150, with approximately 60 alien species estimated to occur in the area. The curve for SOBS is still rising steadily though, with only 66% of the potential species being recorded (Figure 15). The pattern is similar for burned plots (Figure 15).

These simulations clearly show that plot sizes of 0.1 ha are inadequate for conducting an inventory. If a plot size of 0.1 ha were adequate the curves for SOBS and ICE would be converging near the upper end of the range of the total number of samples. This is clearly not the case, therefore it will be absolutely necessary to increase plot size. In simulations of species accumulation curves plot sizes based on both the NRI and TNC data, the mean ***cumulative*** number of species for plot sizes of 1.0 ha is 7 – 14 X higher than plots 0.1 ha in area (Figures 14 and 15). For burned plots, the 1.0 ha plots are 9 – 25 X higher than 0.1 ha plots. This dramatically reduces the sampling effort to conduct an inventory with acceptable levels of accuracy, comprehensiveness, and precision (Table 11). It is important to note that the cumulative mean number of species/unit area represented by the curves in Figures 14 and 15 are not the number of species one would expect to find in a plot of that size. Finding 18 alien species in a 1.0 ha plot would be highly desirable in an inventory program, but is extremely improbable. The curves are most correctly interpreted as the increase in sampling efficiency expected from using a plot of that size.

Based on the estimated sample sizes in Table 11, we recommend that a minimum of 150 1.0 ha plots be used to inventory alien plants in burned areas in Yosemite National Park. Because this minimum number is an empirically derived estimate, we also recommend that a minimum of 50 additional plots be kept “in reserve” if there are indications that the inventory is not approaching the NPSIMP goal of documenting 90% of species expected to occur in the park. If the inventory is to be extended to include alien species in unburned areas that have not been impacted severely by anthropogenic disturbances (e.g. “wilderness” areas), then a minimum of 400 plots will likely be needed.

A square plot with dimensions of 100 m x 100 m is justified given the plot's large area. Rectangular plots have been shown to be better for detecting less common species with an associated lower variance for abundance estimates (e.g. cover, density) (Elzinga et al. 1998). The analysis of the number of species in different shapes of plots in the TNC data set supports this finding, but using a rectangular shaped plot of this size would present practical difficulties in the field. However, rectangular shaped subplots nested within the main 1.0 ha plot would likely be an efficient way of estimating cover of alien species. Since all the alien species that occurred in both data sets were herbaceous, cover (as opposed to density) is the most appropriate measure of abundance. Protocols for estimating cover of alien species within the 1.0 ha plots are described in the *Sampling Protocols* section.

B.5. Literature Review

A database of 207 references from the literature search has been compiled and entered into EndNote. We identified 130 of these references as being the most pertinent for Yosemite National Park (page 97). They focus on invasions into areas of disturbance in the United States, although several that pertain to other Mediterranean ecosystems were included as well. A review of the papers in this database is given in Section VI, and a complete bibliography of all 207 papers we found relating to fire, riparian ecosystems, and invasive species follows the literature review.

C. DISCUSSION

Ideally, the best data to use for designing an inventory protocol for alien species in burned and riparian areas would be from plots in burned areas and riparian communities that had been sampled over a series of years post-disturbance (i.e. burning or flooding). These data were not available, but the NRI and TNC data sets were adequate substitutes, at least for the burned plots. Between them, we were able to derive groups of species associations and their relationship with particular environmental variables. Because these associations and variables were at least qualitatively consistent between the two data sets, it is likely that they represent legitimate ecological patterns and relationships. It also gave us justification for using them as inputs for the predictive modeling component of this project.

Probably the greatest strength of the NRI data set was the sampling protocol and the immense amount of information contained within it. This enabled us to thoroughly analyze general community level patterns and relate these to various physiographic features of the landscape. Ironically, the greatest weakness of the NRI data set was the paucity of alien species. This was because there was a low number of plots in grasslands and meadows, which is the vegetation type with the greatest proportional occurrence of alien species. This was simply an aspect of the data inherent in the way plot locations were selected. The sampling design of the NRI surveys was quite good, and it highlights the clear (and welcome) conclusion that alien species are not particularly common in much of the backcountry of Yosemite. This is similar to a conclusion reached by Gerlach et al. (2001).

The TNC data set had a far greater number of alien species, and this was because of the high proportion of plots in grasslands and meadows. Consequently, most of the information on species associations among alien species and their correlation with physiographic variables came from this data set. Nevertheless, confidence in these patterns is not as great as we would have liked. It was more a matter of good luck than anything else that this data was usable. Although using plots with different size and shapes can be justified for phytosociological studies (which was the goal of the TNC study), this approach makes analysis of ecological patterns extremely tenuous. If species richness of aliens had been correlated with plot size and shape as it was for natives, the data set would not have been used. In reality, the lack of correlation may be a statistical artifact; a relationship did not exist because of the relative rarity of alien species, so statistical power was low. There may actually have been some confounding of plot size with the patterns of alien distribution and abundance, but we could not detect it.

One aspect of the analysis that gives us more confidence that the data from the TNC plots did reflect legitimate ecological patterns is the consistency between it and the NRI data. The variables that emerged as being important for predicting the occurrence and abundance of alien species were similar for both data sets. Although the relative importance of these variables changed somewhat, this was to be expected given the differences in the design of the two studies. If there had been major discrepancies, then inclusion of the variables from the TNC set into the GIS analysis would not have been justified. As it stands, we are cautiously optimistic these variables have legitimate predictive power for where alien species are most likely to occur.

The physiographic variables that had the greatest correlation with distribution and abundance patterns of alien species were elevation, slope, and vegetation structure. These were important in the logistic and linear regressions as well as the CCA's. Soil variables were also important in most of the analyses, however the relative importance of these variables changed substantially from analysis to analysis. We strongly suspect that soil itself was not as important as some other variable correlated with soil type. We believe this is most likely to be soil moisture, or possibly soil depth. The patterns in the CCA's and TWINSPAN's suggested strongly that many of the species were distributed along a moisture gradient. Unfortunately, data on soil moisture or depth were not available, so this remains speculation.

Variables correlated with distribution and abundance patterns of all species (native + alien) did not have as great of a correlation for just alien species. This implies that the environmental conditions alien species are responding to differ at least in magnitude if not kind from native species. For instance, elevation had the strongest correlation with species distribution and abundance patterns in the park. While elevation was correlated with alien species distribution and abundance patterns, its effect was not as strong on them. This is probably because most alien species occurred below 2,700 m (mean = 1561 m). The vegetation formations with the lowest occurrence and cover of alien species were in upper elevation areas (sub-alpine conifer forest and upper montane conifer forest).

Similarly, variables relating to burns (e.g. burn size) were correlated with general patterns of species distribution and abundance (natives + aliens). But burn size (and other burn variables) was not related to patterns of alien species distribution and abundance. Although the species richness and cover of aliens was higher in burned areas than unburned areas, there did not seem to be a correlation with *what* alien species occurred in burned areas. Vegetation structure was a much better predictor of species associations among aliens. The implication is that alien species that occur in a burned area are not ones that are necessarily invading the site because it burned, but because the area was already infested and the alien species that were present increased in abundance after the fire. We want to emphasize that this is only a hypothesis and it needs to be experimentally tested. But if it is true it has tremendous importance for implementation and management of fire in the park.

Using re-sampling techniques to help determine sample and plot sizes worked reasonably well. There are other ways to calculate sample size, the most common being fitting data to a statistical distribution. Fitting the NRI and TNC data to a negative binomial distribution was the initial step in this part of our analysis. Given the shape of the distribution, the fit of our data to the model, and the large number of plots in each data set, we are confident that the negative binomial was a useful model of alien species distribution patterns. But using a statistical distribution limits inferences to the parameters used to fit the empirical data to the model. Re-sampling tests such as the bootstrap allow greater flexibility for exploring how sample size would change if the empirical data were modified, such as we did by looking at sampling efficiency relative to plot size.

Bootstrapping of the NRI data was of limited usefulness because neither the curve for the number of alien species observed nor the estimated number of alien species reached an asymptote. This was due entirely to the small number of plots with alien species present in the NRI data set. But the curves for the estimated number of alien species in all the TNC plots (burned + unburned) as well as the burned plots started to reach an asymptote. This was especially pronounced for the curve for all the TNC plots. It is interesting to note that although the asymptote for the burned TNC plots was not as pronounced as that for all of the TNC plots, it was starting to flatten out in the same range as the curve for all the plots. It appears as if an upper estimate of 60 alien species that could potentially occur in the inventory appears reasonable. Based on the NRI and TNC data sets, the minimum number of alien species known to be in burned areas is 36. Therefore, an inventory of alien species should expect to find no less than 36 and no more than 60.

The lack of data for riparian areas prevented us from doing any analyses of relationships of alien species with flooding. However, we believe this situation presents more of an opportunity than it does an obstacle. There is a clear need for such data, and we have suggested a sampling design for riparian areas (see *Sampling Protocol and*

Statistical Analysis section). The sampling protocol would be independent of that for burned areas, but because inferences and interpretation of patterns are enhanced when data are collected under similar environmental conditions (e.g. annual or multi-year weather patterns), we strongly encourage that they be implemented at the same time, or within a few years of one another. We also want to emphasize that this design is based on inferences from the analysis of aliens in burned areas. These inferences are that alien species will be relatively uncommon, and that a substantial sampling effort will be required to conduct an inventory.

In conclusion, the evidence from these data indicates that the distribution of alien species in Yosemite National Park depends primarily on physical (elevation, slope) and biological (vegetation structure) variables. There was no consistent evidence that disturbance has a major effect on distribution of alien species. A synthesis of the CCA, TWINSPAN and logistic regression analyses indicates that there are three main groups of alien species that tend to co-occur. One group, characterized by *Bromus tectorum* and *Vulpia myuros*, occurs most commonly in steeper shrub and open conifer forest associations on drier slopes. The second group is characterized by *Poa pratensis* and occurs most frequently in relatively flat areas with high amounts of herbaceous cover, such as meadows. The third group is less well defined than the other two, and it appears to intergrade with areas where *Poa pratensis* occurs. This third group is characterized by *Holcus lanatus*, *Cirsium vulgare*, and *Rumex acetosella*. The overwhelming majority of alien species occur sporadically and at low abundance, and even the most abundant can not be considered "community dominants". There is no evidence that abundance of alien species is correlated with general patterns of species diversity. This reduces concern over alien species invading areas of high species diversity ("hot spots"). Although there is legitimate concern that alien species could negatively affect fire regimes in western montane forests (Crawford et al. 2001, Keeley 2001), the current data suggest that alien species are not having a strong effect on fire regimes in Yosemite at this time. However, because alien species in Yosemite National Park occur at low abundance and have restricted distributions, substantial time and effort will need to be allocated to an inventory program so that sampling is adequate enough to statistically analyze the data.

D. SAMPLING PROTOCOLS AND STATISTICAL ANALYSIS

D.1. Burned Plots

Sampling will be conducted in 1.0 ha plots that are 100 m x 100 m in dimension. The plots will be oriented in the four cardinal directions, and one of the four sides will be randomly selected as the "primary side" of the plot. The side opposite and parallel to the primary side will be designated the "secondary side". A point between 1 m and 50 m will be randomly selected on the primary side. From this point, a 100-m baseline perpendicular to the primary side will be laid out between the primary and secondary sides. A point on the baseline between 1 m and 15 m from the primary side will be randomly selected. From this point, 10 belt transects 50 m x 2 m in dimension will be run parallel to the primary and secondary sides. The belt transects will be spaced 5 m apart. A diagram of the plot is given in Appendix 1.

After laying out the transects, a crew of 2 – 4 people will perform the sampling in each plot. Several hours will be spent doing a complete inventory of all alien species within the plot. Observers will move systematically through the plot and list all alien species that are encountered (presence/absence). If time and budget permit, we strongly encourage native species to be included in the sampling as well. The greatest threat from alien species are their potential impacts on native species, and collecting data for both native and alien species will allow this to be analyzed.

Once the list of all alien species in the plot is completed, several more hours will be spent estimating cover of alien species. Again, if time and budget permit, we strongly encourage cover of native species to be estimated. The transects will be broken up into 25 subplots that are 2 m x 2 m in dimension. Within each subplot each species (alien or native, depending on time and budget) will be assigned a Daubenmire cover value (Bonham 1989). Species that occur in the inventory of the entire plot but don't occur in the transects will be given a cover value of 0.01% for the entire plot. The mean of the 25 Daubenmire values will be the estimate of cover for any given species for that *transect* (50m x 2m). Based on the experience of one of the authors (RK), we estimate that a crew of two people will be able to complete one plot/8 –10 hrs. This estimate does not include time to access the plot, and assumes the crew is familiar with plant species in the park. A sample field data sheet is given in Appendix 2.

The elevation, aspect and slope for each plot can be collected on site with a compass and/or GPS. These data can then be checked against GIS calculations. We also strongly encourage collection of data in each plot on vegetation structure. The number and height of shrubs and trees can be made by counting the number of stems rooted within the belt transects (ramets) and assigning each one to a cover height class. We strongly discourage using cover estimates rather than shrub and tree counts. Density is often a more meaningful measure of vegetation structure in shrub and forested communities than cover is. As cover approaches 100%, stem density can continue to increase while cover does not. So, cover in two plots can be 100% but the stem density between the plots can be very different. If desired, cover for different vegetation layers can be derived from the Daubenmire value estimates that were made in the transects (which is another reason we urge collection of data on all species). Finally, we recommend soil depth be sampled at 10 – 12 random locations within each plot, and that samples be collected for estimates of soil moisture or water holding capacity. Soil moisture values will change over the time it takes to conduct the vegetation sampling. So, soil moisture data collected at the same time vegetation data are will be confounded by time. Therefore, we recommend that soil samples be collected in a two-week period before the floristic surveys begin. Alternatively, soil moisture holding capacity could be determined from the samples if funding allowed it.

The advantage of this design is that it permits estimation of variability of cover and occurrence of alien species both within and between plots. The plots are large enough that they will likely have one or more alien species in them, and the rectangular shape of the subplots will increase the likelihood of reducing variability in cover estimates for the alien species. Finally, distribution and abundance patterns for alien species can be correlated with the physiographic variables which data were collected for at each plot, as well as with data for native species.

Data analysis should initially concentrate on determining species accumulation curves. Similar to the approach we used in this study, the cumulative number of species can be plotted against the number of plots sampled. As the species accumulation curve begins to flatten out, adding more samples will not increase the likelihood of finding substantially more species. At this point sampling can cease. Two programs that are recommended for these types of analysis are EstimateS and BioDiversity Pro. Both have resampling capabilites, they are user friendly, and results from each can be imported as tables into spreadsheet programs. They are both available without cost from over the internet.

Further data analysis should emphasize the relationships between alien species distribution and abundance patterns and physiographic variables. Statistical methods used in this study would be appropriate (CCA, logistic regression).

D.2. Riparian Plots

Sampling in riparian areas will emphasize presence/absence of alien species. Although it is tempting to suggest an approach for estimating cover of aliens, this may be a waste of time and effort without first knowing how alien species are distributed within riparian areas.

From a starting point located by the GIS, a 500 m x 20 m (1 ha) belt transect will be centered along a stream. The transect will extend 10-m out from both edges of the watercourse. If necessary, the observers can narrow the width of the transect to stay within the riparian boundaries. If they do this, the length of the belt should be extended so the total plot area remains a close approximation of 1 ha. Two observers, one on each side of the stream, will walk within the 10-m belt and record all alien species they encounter. Frequency categories can be assigned to each species. Accurate positioning of the plots with GPS units can be used to calculate topographic features, such as elevation, stream order, and stream gradient. A sample data sheet is given in Appendix 3.

Statistical analysis can follow the same general approach recommended for plots in burned areas.

E. ASSESSMENT AND SUMMARY

- Alien species comprise a relatively minor component of the vegetation communities in areas of Yosemite where human activity is low. This is good from a management and conservation perspective, but it will require substantial sampling effort to obtain a meaningful inventory of alien species in burned areas.

- Most occurrences of alien species are in low to mid-elevation vegetation associations and habitat types. Alien species are not restricted to a particular vegetation structure or habitat type, but they do not appear to be exploiting areas that have burned.
- The variables that are most strongly correlated with the occurrence of alien species are best used to predict where alien species do *not* occur. Areas where alien species are least likely to occur are high elevation sites such as sub-alpine conifer forest and upper montane conifer forest.
- Elevation, slope, and the relative amounts of woody and herbaceous cover are the gradients that have the strongest correlation with the distribution and abundance of alien species. It is likely that soil moisture and possibly soil depth have a strong correlation with distribution and abundance patterns of alien species, but data do not presently exist to test this.
- There are probably three main assemblages of alien species. Two of these tend to occur most frequently in mesic meadows and open areas, and the third in drier shrublands, woodlands and forests.
- Extensive sampling will be required to record 90% of the alien species known to occur in the park. Although not as great an effort will be required conducting an inventory within burned areas, it will still require a minimum of 150 plots, and maybe as many as 200 or even more. However, the intensity of sampling effort can be decreased substantially by increasing the size of the inventory plot from 0.1 ha to 1.0 ha.
- There has not been enough data collected in riparian areas to justify (or allow) any quantitative analysis. A design for sampling protocols for inventorying alien species in riparian areas has been suggested.

F. TABLES, FIGURES AND APPENDICES

Table 1. Similarity in species composition between plots of different size and shape in Yosemite National Park, California. The data are from a TNC vegetation classification study done in 1998 and 1999. S Obs = species observed, and Morisita-Horn is the Morisita-Horn index of similarity. Rec=rectangular shaped plots and Sqr=square shaped plots. Plot sizes were 100, 400, and 1000 m^2. Size/shape combinations were bootstrapped 50 times (see Methods section).

All Species

FirstSample	SecondSample	SObsFirst	SObsSecond	SharedObs	Morisita-Horn
Rec100	Sqr100	236	212	144	0.64
Rec100	Rec400	236	286	131	0.50
Rec400	Sqr100	286	212	123	0.49
Rec400	Sqr400	286	262	129	0.47
Rec400	Rec1000	286	468	170	0.45
Rec1000	Sqr400	468	262	155	0.42
Rec100	Rec1000	236	468	138	0.39
Rec100	Sqr400	236	262	90	0.36
Rec1000	Sqr100	468	212	118	0.35
Sqr100	Sqr400	212	262	83	0.35
Rec1000	Sqr1000	468	61	57	0.22
Rec400	Sqr1000	286	61	30	0.17
Sqr400	Sqr1000	262	61	27	0.17
Rec100	Sqr1000	236	61	18	0.12
Sqr100	Sqr1000	212	61	15	0.11

Native Species

FirstSample	SecondSample	SObsFirst	SObsSecond	SharedObs	Morisita-Horn
Rec100	Sqr100	230	268	127	0.51
Rec100	Rec400	230	443	134	0.40
Rec400	Sqr100	230	209	141	0.64
Rec400	Sqr400	230	235	85	0.37
Rec400	Rec1000	230	59	17	0.12
Rec1000	Sqr400	268	443	162	0.46
Rec100	Rec1000	268	209	121	0.51
Rec100	Sqr400	268	235	115	0.46
Rec1000	Sqr100	268	59	28	0.17
Sqr100	Sqr400	443	209	116	0.36
Rec1000	Sqr1000	443	235	141	0.42
Rec400	Sqr1000	443	59	55	0.22
Sqr400	Sqr1000	209	235	80	0.36
Rec100	Sqr1000	209	59	13	0.10
Sqr100	Sqr1000	235	59	25	0.17

Table 1 continued.

Alien Species

FirstSample	SecondSample	SObsFirst	SObsSecond	SharedObs	Morisita-Horn
Rec100	Sqr100	6	18	4	0.33
Rec100	Rec400	6	25	4	0.26
Rec400	Sqr100	6	2	2	0.50
Rec400	Sqr400	6	27	5	0.30
Rec400	Rec1000	6	2	1	0.25
Rec1000	Sqr400	18	25	8	0.37
Rec100	Rec1000	18	2	1	0.10
Rec100	Sqr400	18	27	14	0.62
Rec1000	Sqr100	18	2	2	0.20
Sqr100	Sqr400	25	2	1	0.07
Rec1000	Sqr1000	25	27	14	0.54
Rec400	Sqr1000	25	2	2	0.15
Sqr400	Sqr1000	2	27	2	0.14
Rec100	Sqr1000	2	2	1	0.50
Sqr100	Sqr1000	27	2	2	0.14

Table 2. Similarity in species composition between burned and unburned plots from NRI and TNC data sets at Yosemite National Park, California. S Obs = species observed, and Morisita-Horn is the Morista-Horn index of similarity.

FirstSample	SecondSample	SObsFirst	SObsSecond	SharedObs	Morisita-Horn
Burned NRI	Unburned NRI	14	9	6	0.86
Burned NRI	Total NRI	14	17	14	0.98
Burned NRI	Burned TNC	14	32	9	0.49
Burned NRI	Unburned TNC	14	30	10	0.46
Burned NRI	Total TNC	14	41	11	0.49
Unburned NRI	Total NRI	9	17	9	0.94
Unburned NRI	Burned TNC	9	32	7	0.67
Unburned NRI	Unburned TNC	9	30	7	0.69
Unburned NRI	Total TNC	9	41	7	0.69
Total NRI	Burned TNC	17	32	10	0.59
Total NRI	Unburned TNC	17	30	11	0.57
Total NRI	Total TNC	17	41	12	0.59
Burned TNC	Unburned TNC	32	30	21	0.90
Burned TNC	Total TNC	32	41	32	0.98
Unburned TNC	Total TNC	30	41	30	0.97

Table 3. Distribution (number of plots) and abundance (mean cover values) for 46 alien species recorded at Yosemite National Park in 356 NRI plots (1989 – 1993) and 236 TNC plots (1998 – 1999).

	NRI Plots				TNC Plots			
	Burned		Unburned		Burned		Unburned	
Species	Cover (%)	# Plots	Cover (%)	# Plots	Cover (%)	# Plots	Cover (%)	# Plots
Agrostis capillaris L.					0.50	1	2.50	1
Agrostis gigantea Roth					37.50	1	2.50	1
Agrostis stolonifera L.					8.75	2	0.00	0
Aira caryophyllea L.	0.72	3	0.72	3	0.50	3	0.50	1
Bromus arenarius Labill.					1.50	2	0.50	1
Bromus diandrus Roth.	1.00	1	1.00	1	0.50	1	0.50	1
Bromus hordeaceous L.	0.17	2	0.17	2	2.50	1	8.75	2
Bromus japonicus Thunb. ex Murr.	0.17	1	0.17	1	0.00	0	1.50	2
Bromus rubens L.					0.50	1	0.00	0
Bromus sterilis L.					0.00	0	0.00	1
Bromus tectorum L.	0.99	10	0.99	10	4.63	8	1.50	6
Centaurea cyanus L.					0.50	1	0.00	0
Cerastium glomeratum Thuill.					0.00	0	0.50	1
Cirsium vulgare (Savi) Ten.	1.00	2	1.00	2	1.17	6	0.50	3
Citrullus lanatus var. lanatus (Thunb.) M. & N.					0.00	0	0.50	1
Dianthus armeria L.					0.50	1	0.50	2
Erodium cicutarium (L.) L'Her. ex Ait.					0.50	1	2.50	1
Galium parisiense L.					0.50	1	0.00	0
Holcus lanatus L.	1.67	1	1.67	1	1.30	5	1.00	4
Hypericum perforatum L.					0.50	1	0.00	0
Hypericum scouleri ssp. scouleri Hook.					1.17	3	0.50	2
Hypochoeris glabra L.	0.17	1	0.17	1				
Lactuca serriola L.					0.90	5	0.50	2
Leucanthemum vulgare Lam.	0.83	1	0.83	1	0.50	3	0.00	0
Myosotis discolor Pers.					0.00	0	0.50	2
Phalaris aquatica L.					2.50	1	0.00	0
Phleum pratense L.					0.50	3	0.50	4
Plantago lanceolata L.	0.83	1	0.83	1	0.00	0	2.50	1
Poa annua L.					0.00	0	0.50	1
Poa bulbosa L.	0.00	0	0.00	0				
Poa compressa L.					0.00	0	2.50	1
Poa nemoralis L.					15.00	1	0.00	0
Poa pratensis L.	3.75	2	3.75	2	11.27	13	9.73	13
Rubus discolor Weihe & Nees					2.50	1	0.50	1
Rumex acetosella L.	0.00	0	0.00	0	6.86	11	6.00	6
Rumex crispus L.					1.00	4	0.50	1
Silene gallica L.					0.00	0	0.50	1
Sisymbrium altissimum L.	0.00	0	0.00	0				
Spergularia rubra (L.) J.S. Presl & C. Presl.	0.42	1	0.42	1				
Taraxacum officinale G.H. Weber ex Wiggers					0.50	2	0.50	1
Torilis arvensis (Huds.) Link					0.50	1	0.50	1

Table 3 continued.

	NRI Plots				TNC Plots			
	Burned		Unburned		Burned		Unburned	
Species	Cover (%)	# Plots	Cover (%)	# Plots	Cover (%)	# Plots	Cover (%)	# Plots
Tragopogon dubius Scop.					0.50	2	0.00	0
Trifolium repens L.					0.50	1	0.00	0
Vinca major L.					0.50	1	0.00	0
Vulpia bromoides (L.) S. F. Gray	0.17	2	0.17	2	0.00	0	0.00	0
Vulpia myuros (L.) K.C. Gmel.	1.15	10	1.15	10	7.33	6	6.67	3

Table 4. The occurrence of alien plant species in vegetation associations at Yosemite National Park, California. The data are from NRI and TNC studies conducted from 1989 – 1993 and 1998 – 1999, respectively.

	Alien Species Not Present		Alien Species Present			
Formation/Alliance	N	%	N	%	Total	% Total
NRI Data						
Subalpine Conifer Forest						
Whitebark Pine	18	5.1	0	0.0	18	5.1
Lodgepole Pine	85	23.9	4	1.1	89	25.0
Whitebark Pine-Lodgepole Pine	2	0.6	1	0.3	3	0.8
Whitebark Pine-Mountain Hemlock	1	0.3	0	0.0	1	0.3
Mountain Hemlock	7	2.0	0	0.0	7	2.0
Upper Montane Conifer Forest						
Red Fir	21	5.9	2	0.6	23	6.5
Western White Pine	9	2.5	0	0.0	9	2.5
Jeffrey Pine	19	5.3	4	1.1	23	6.5
Jeffrey Pine-Fir	16	4.5	2	0.6	18	5.1
Lower Montane Conifer Forest						
Westside Ponderosa Pine	22	6.2	2	0.6	24	6.7
Ponderosa Pine Mixed Conifer	19	5.3	3	0.8	22	6.2
Ponderosa Pine-Mixed Conifer	0	0.0	0	0.0	0	0.0
White Fir Mixed Conifer	11	3.1	0	0.0	11	3.1
White Fir-Mixed Conifer	0	0.0	0	0.0	0	0.0
Douglas Fir Mixed Conifer	5	1.4	1	0.3	6	1.7
Douglas Fir-Mixed Conifer	0	0.0	0	0.0	0	0.0
Sierra White Fir	3	0.8	0	0.0	3	0.8
Giant Sequoia Mixed Conifer	1	0.3	0	0.0	1	0.3
Broadleaved Upland Forests and Woodlands						
California Black Oak Woodland/Forest	3	0.8	0	0.0	3	0.8
Broadleaved Upland Forests						
Canyon Live Oak	8	2.2	3	0.8	11	3.1
Aspen	2	0.6	0	0.0	2	0.6
Broadleaved Upland Woodlands						
Foothill Pine-Live-Oak-Chaparral Woodland	2	0.6	9	2.5	11	3.1
Cismontane Juniper Woodland	1	0.3	0	0.0	1	0.3
Scrub and Chaparral Communities						
Montane Chaparral	5	1.4	0	0.0	5	1.4
Northern Mixed Chaparral	2	0.6	0	0.0	2	0.6
Montane And Alpine Riparian Scrub	2	0.6	0	0.0	2	0.6
Grasslands and Meadows						
Subalpine And Alpine Meadow	24	6.7	1	0.3	25	7.0
Subalpine And Alpine Meadows	0	0.0	0	0.0	0	0.0
Montane Meadow	2	0.6	1	0.3	3	0.8
Bermuda Turf	0	0.0	0	0.0	0	0.0
Barren						
Barren	30	8.4	3	0.8	33	9.3
Total	320	89.9	36	10.1	356	100.0

Table 4 continued.

	Alien Species Not Present		Alien Species Present			
Formation/Alliance	N	%	N	%	Total	% Total
TNC Data						
Subalpine Conifer Forest						
Whitebark Pine	9	3.8	0	0.0	9	3.8
Lodgepole Pine	51	21.6	3	1.3	54	22.9
Whitebark Pine-Lodgepole Pine	1	0.4	0	0.0	1	0.4
Whitebark Pine-Mountain Hemlock	0	0.0	0	0.0	0	0.0
Mountain Hemlock	5	2.1	0	0.0	5	2.1
Upper Montane Conifer Forest						
Red Fir	20	8.5	2	0.8	22	9.3
Western White Pine	0	0.0	0	0.0	0	0.0
Jeffrey Pine	6	2.5	0	0.0	6	2.5
Jeffrey Pine-Fir	4	1.7	6	2.5	10	4.2
Lower Montane Conifer Forest						
Westside Ponderosa Pine	1	0.4	22	9.3	23	9.7
Ponderosa Pine Mixed Conifer	6	2.5	1	0.4	7	3.0
Ponderosa Pine-Mixed Conifer	0	0.0	0	0.0	0	0.0
White Fir Mixed Conifer	11	4.7	5	2.1	16	6.8
White Fir-Mixed Conifer	0	0.0	0	0.0	0	0.0
Douglas Fir Mixed Conifer	1	0.4	3	1.3	4	1.7
Douglas Fir-Mixed Conifer	0	0.0	0	0.0	0	0.0
Sierra White Fir	3	1.3	0	0.0	3	1.3
Giant Sequoia Mixed Conifer	1	0.4	0	0.0	1	0.4
Broadleaved Upland Forests and Woodlands						
California Black Oak Woodland/Forest	1	0.4	1	0.4	2	0.8
Broadleaved Upland Forests						
Canyon Live Oak	0	0.0	0	0.0	0	0.0
Aspen	0	0.0	0	0.0	0	0.0
Broadleaved Upland Woodlands						
Foothill Pine-Live-Oak-Chaparral Woodland	1	0.4	1	0.4	2	0.8
Cismontane Juniper Woodland	0	0.0	0	0.0	0	0.0
Scrub and Chaparral Communities						
Montane Chaparral	2	0.8	0	0.0	2	0.8
Northern Mixed Chaparral	0	0.0	2	0.8	2	0.8
Montane And Alpine Riparian Scrub	0	0.0	0	0.0	0	0.0
Grasslands and Meadows						
Subalpine And Alpine Meadow	37	15.7	0	0.0	37	15.7
Montane Meadow	6	2.5	10	4.2	16	6.8
Bermuda Turf	0	0.0	1	0.4	1	0.4
Barren						
Barren	13	5.5	0	0.0	13	5.5
Total	179	75.8	57	24.2	236	100.0

Table 5. Results of logistic regression analysis of the incidence (presence/absence) of alien plant species in NRI and TNC plots at Yosemite National Park, California.

Regression Statistics – NRI Data (1989 – 1993)

Parameter	Coefficient	SE Coefficient	t	p	Odds Ratio	95% CI Odds Ratio
Elevation	-0.001	0.000	6.03	<0.001	1.00	± 0.001
Tree Species	0.495	0.224	2.21	0.027	1.64	± 0.740
Shrub Species	0.534	0.270	1.98	0.048	1.71	± 0.945
Herbaceous Species	0.198	0.046	4.31	<0.001	1.22	± 0.105
Sand (%)	-0.315	0.105	3.02	0.003	0.73	± 0.151
Loam (%)	0.315	0.144	2.19	0.029	1.37	± 0.068

Classification Table – NRI Data (1989 – 1993)

	Predicted Classification		Total Number of Plots
Alien Species	Present	Not Present	
Present	19	17	36
Not Present	17	303	320

Regression Statistics – TNC Data (1998 – 1999)

Parameter	Coefficient	SE Coefficient	t	P	Odds Ratio	95% CI Odds Ratio
Elevation	-0.004	0.001	5.54	<0.001	0.996	± 0.002
Slope	-0.092	0.043	2.15	0.031	0.912	± 0.077
Cobble (%)	-0.409	0.154	2.65	0.008	0.664	± 0.204
Herbaceous Cover (%)	0.018	0.009	1.95	0.051	1.018	± 0.017

Classification Table – TNC Data (1998 – 1999)

	Predicted Classification		Total Number of Plots
Alien Species	Present	Not Present	
Present	36	20	56
Not Present	20	160	180

Table 6. Multiple regression statistics of the relationship between alien species richness and cover and different environmental variables from NRI and TNC data sets at Yosemite National Park, California.

NRI Data – species richness

Adjusted R^2 = 0.391, df=6,29, p=0.002

Variable	Coefficient	Coefficient SEM	t	p
Elevation	-0.001	0.000	2.42	0.022
Tree Species	-0.025	0.015	1.730	0.094
Shrub Species	-0.005	0.020	0.238	0.814
Herbaceous Species	0.020	0.004	4.396	0.000
Sand (%)	0.001	0.011	0.069	0.945
Loam (%)	-0.002	0.012	0.132	0.896

NRI Data – % Cover

Adjusted R^2 = 0.063, df=6,29, p=0.251

Variable	Coefficient	Coefficient SEM	t	p
Elevation	0.000	0.000	0.103	0.919
Tree Species	-0.028	0.027	1.041	0.307
Shrub Species	0.008	0.036	0.225	0.823
Herbaceous Species	0.015	0.008	1.845	0.075
Sand (%)	-0.033	0.019	1.673	0.105
Loam (%)	0.031	0.021	1.450	0.158

TNC Data – species richness

Adjusted R^2 = 0.242, df=4,51, p=0.001

Variable	Coefficient	Coefficient SEM	t	p
Elevation	-0.001	0.000	4.540	0.000
Slope	0.006	0.005	1.099	0.277
Cobble (%)	0.007	0.017	0.431	0.668
Herbaceous Cover	0.002	0.001	1.940	0.058

TNC Data – % Cover

Adjusted R^2 = 0.324, df=4,51, p=0.000

Variable	Coefficient	Coefficient SEM	T	p
Elevation	-0.001	0.000	4.965	0.000
Slope	0.004	0.012	0.352	0.727
Cobble (%)	-0.008	0.040	0.204	0.840
Herbaceous Cover	0.007	0.002	3.417	0.001

Table 7. Forward stepping multiple regression statistics for environmental variables used in CCA's of species distribution patterns in NRI and TNC plots at Yosemite National Park, California. Variables in bold had a significant correlation with distribution and abundance patterns of species.

All Species				*Alien Species*			
A. NRI Data							
Variable	Lambda	F	P	Variable	Lambda	F	P
Elevation	0.68	23.41	0.005	**Cobble (%)**	0.84	4.64	0.010
Tree Cover (%)	0.14	5.01	0.005	**Herbaceous Cover (%)**	0.67	4.05	0.030
Herbaceous Cover (%)	0.13	4.58	0.005	Burn Edge Ratio	0.40	2.52	0.070
Shrub Cover (%)	0.11	3.90	0.005	**Elevation**	0.32	2.08	0.040
Slope	0.08	2.82	0.015	**Aspect**	0.36	2.42	0.010
% Boulder	0.07	2.69	0.005	**Slope**	0.31	2.22	0.020
% Loam	0.06	2.24	0.005	Stone (%)	0.23	1.63	0.150
Aspect	0.06	2.14	0.005	Burn Size (ha)	0.20	1.49	0.160
% Sand	0.06	2.02	0.015	Shrub Cover (%)	0.19	1.45	0.130
Burn Perimeter (m)	0.04	1.55	0.050	Sand (%)	0.15	1.10	0.320
Burn Size (ha)	0.05	1.75	0.010	Loam (%)	0.17	1.33	0.220
% Gravel	0.03	1.27	0.110	Tree Cover (%)	0.13	0.94	0.460
Years Post-burn	0.03	1.08	0.285	Years Postburn	0.10	0.77	0.620
Burn Edge Ratio	0.03	1.05	0.335	Gravel (%)	0.06	0.48	0.820
% Stone	0.02	0.84	0.800	Boulder (%)	0.10	0.73	0.680
% Cobble	0.03	1.07	0.310	Burn Perimeter	0.03	0.18	0.960
B. TNC Data							
Elevation	0.71	6.41	0.005	**Shrub Cover (%)**	0.45	3.44	0.005
Herbaceous Cover (%)	0.47	4.36	0.005	% Boulder	0.25	1.94	0.055
Tree Height (m)	0.29	2.61	0.005	**Elevation**	0.24	1.88	0.045
Burn Size (ha)	0.24	2.27	0.015	**Slope**	0.23	1.88	0.040
Herbaceous Height (cm)	0.21	1.92	0.005	**Tree Cover (%)**	0.22	1.73	0.015
Shrub Cover (%)	0.20	1.88	0.005	% Cobble	0.17	1.42	0.140
Burn Perimeter (m)	0.16	1.51	0.045	Burn Size (ha)	0.16	1.37	0.125
Slope	0.16	1.45	0.025	Herbaceous Cover (%)	0.16	1.28	0.215
% Loam	0.13	1.30	0.035	% Loam	0.15	1.23	0.205
% Cobble	0.14	1.32	0.080	Shrub Height (m)	0.12	1.07	0.365
% Gravel	0.13	1.21	0.095	Aspect	0.12	0.98	0.490
Aspect	0.12	1.13	0.095	% Sand	0.11	0.87	0.660
Tree Cover (%)	0.12	1.13	0.160	Burn Edge Ratio	0.09	0.75	0.535
Years Post-burn	0.12	1.10	0.230	% Stone	0.08	0.72	0.725
Shrub Height (m)	0.10	0.97	0.460	Burn Perimeter (m)	0.09	0.72	0.770
% Boulder	0.10	0.93	0.530	Years Post-burn	0.10	0.80	0.630
Burn Edge Ratio	0.09	0.87	0.500	Tree Height (m)	0.08	0.64	0.790
% Stone	0.09	0.82	0.910	Herbaceous Height (cm)	0.08	0.66	0.780
% Sand	0.06	0.61	1.000	% Gravel	0.07	0.49	0.945

Table 7 continued.

C. Combined NRI/TNC Data

Variable	Lambda	F	P
Herbaceous Cover (%)	0.46	3.28	0.005
Cobble (%)	0.42	3.08	0.030
Shrub Cover (%)	0.34	2.57	0.030
Boulder (%)	0.33	2.50	0.030
Slope	0.29	2.26	0.005
Elevation	0.27	2.09	0.010
Loam (%)	0.22	1.72	0.105
Tree Cover (%)	0.21	1.63	0.075
Burn Perimeter	0.18	1.48	0.045
Gravel (%)	0.18	1.38	0.075
Aspect	0.16	1.35	0.110
Burn Edge ratio	0.15	1.14	0.300
Stone (%)	0.11	0.95	0.400
Sand (%)	0.17	1.38	0.115
Burn Size (ha)	0.10	0.75	0.465
Years Post-burn	0.10	0.84	0.590

Table 8. Summary statistics for three Canonical Correspondence Analyses of the relationship between environmental variables and the distribution and abundance of alien plant species in NRI plots at Yosemite National Park, California.

(A) All Species and Plots

Statistic	Axes 1	2	3
Eigenvalue	0.706	0.203	0.160
Species/Environmental Variable Correlation	0.959	0.663	0.662
Cumulative % Variation Species Data	6.5	8.3	9.8
Cumulative % Variation Species/Environmental Variable Relationship	47.8	61.5	72.4

(B) Alien Species and Axes From Ordination (A)

Statistic	1	2	3
Eigenvalue	0.790	0.590	0.394
Species/Environmental Variable Correlation	0.903	0.888	0.753
Cumulative % Variation Species Data	12.3	21.5	27.6
Cumulative % Variation Species/Environmental Variable Relationship	30.9	54.0	69.4

(C) Alien Species and Axes Derived From This Ordination

Statistic	1	2	3
Eigenvalue	0.874	0.747	0.458
Species/Environmental Variable Correlation	0.937	0.909	0.779
Cumulative % Variation Species Data	12.5	23.2	29.7
Cumulative % Variation Species/Environmental Variable Relationship	34.5	64.0	82.1

Table 9. Summary statistics for three Canonical Correspondence Analyses of the relationship between environmental variables and the distribution and abundance of alien plant species in TNC plots at Yosemite National Park, California.

(A) All Species and Plots

Statistic	Axes 1	2	3
Eigenvalue	0.734	0.517	0.331
Species/Environmental Variable Correlation	0.969	0.902	0.881
Cumulative % Variation Species Data	2.8	4.7	5.9
Cumulative % Variation Species/Environmental Variable Relationship	28.5	48.6	61.5

(B) Alien Species and Axes From Ordination (A)

Statistic	1	2	3
Eigenvalue	0.630	0.297	0.236
Species/Environmental Variable Correlation	0.929	0.752	0.718
Cumulative % Variation Species Data	8.2	12.1	15.2
Cumulative % Variation Species/Environmental Variable Relationship	35.9	52.8	66.3

(C) Alien Species and Axes Derived From This Ordination

Statistic	1	2	3
Eigenvalue	0.546	0.249	0.205
Species/Environmental Variable Correlation	0.881	0.691	0.693
Cumulative % Variation Species Data	7.1	10.4	13.1
Cumulative % Variation Species/Environmental Variable Relationship	48.5	70.5	88.7

Table 10. Summary statistics for a Canonical Correspondence Analysis of the relationship between environmental variables and the distribution and abundance of alien plant species in NRI and TNC plots at Yosemite National Park, California.

	Axes		
Statistic	1	2	3
Eigenvalue	0.597	0.444	0.368
Species/Environmental Variable Correlation	0.874	0.875	0.771
Cumulative % Variation Species Data	4.5	7.9	10.7
Cumulative % Variation Species/Environmental Variable Relationship	25.8	45.0	61.0

Table 11. Sampling effort required to detect the mean number of alien species/plot for different levels of precision at Yosemite National Park, California. CI = confidence interval, and values in the table are the number of 0.1 ha plots for a given level of precision of the mean within that CI.

NRI Data – All Plots

Percent Estimate of Mean	90% CI	95% CI
5	15,823	22,466
10	3,956	5,616
15	1,758	2,496
20	990	1,404
25	634	901
30	441	625
35	324	461
40	249	353

NRI Data – Burned Plots

Percent Estimate of Mean	90% CI	95% CI
5	9,182	13,037
10	2,296	3259
15	1,020	1,449
20	575	817
25	369	523
30	257	364
35	189	268
40	145	205

TNC Data – All Plots

Percent Estimate of Mean	90% CI	95% CI
5	8020	11,387
10	2005	2847
15	892	1265
20	502	713
25	322	458
30	224	318
35	165	234
40	127	180

Table 11 continued.

TNC Data – Burned Plots

Percent Estimate of Mean	90% CI	95% CI
5	2659	3775
10	666	946
15	297	422
20	168	238
25	108	153
30	76	107
35	56	79
40	43	61

Table 12. Sampling effort required to detect the mean number of alien species/plot for different levels of precision at Yosemite National Park, California. CI = confidence interval, and values in the table are the number of 1.0 ha plots for a given level of precision of the mean within that CI.

NRI Data – All Plots

Percent Estimate of Mean	90% CI	95% CI
5	1,116	1,584
10	279	396
15	124	176
20	70	99

NRI Data – Burned Plots

Percent Estimate of Mean	90% CI	95% CI
5	375	532
10	94	133
15	42	59
20	24	33

TNC Data – All Plots

Percent Estimate of Mean	90% CI	95% CI
5	1217	1729
10	304	432
15	155	192
20	76	108

TNC Data – Burned Plots

Percent Estimate of Mean	90% CI	95% CI
5	398	565
10	100	142
15	45	64
20	25	36

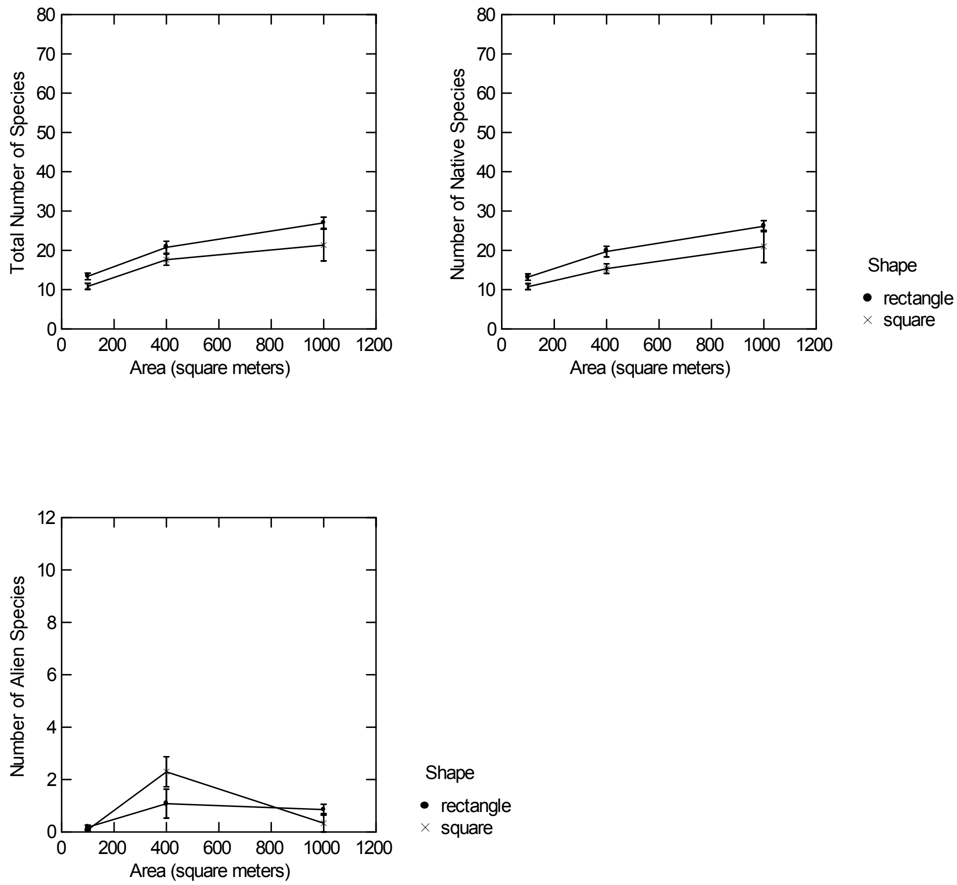


Figure 1. The relationship between species richness of native, alien, and the total number of species (native + alien) in plots of different size and shape at Yosemite National Park, California. The data were collected in 1998 – 1999 during a vegetation classification study by TNC.

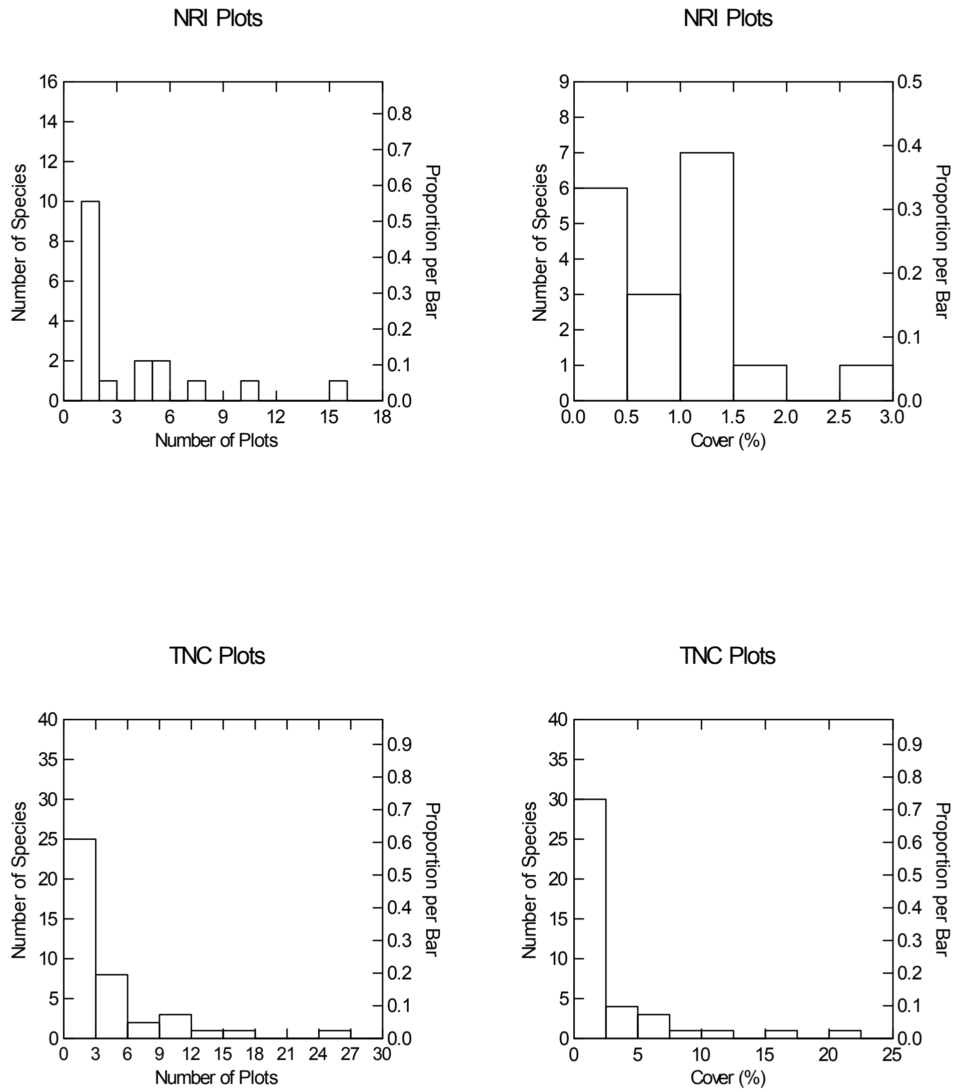


Figure 2. Distribution and abundance patterns of alien species recorded in NRI and TNC plots at Yosemite National Park, California.

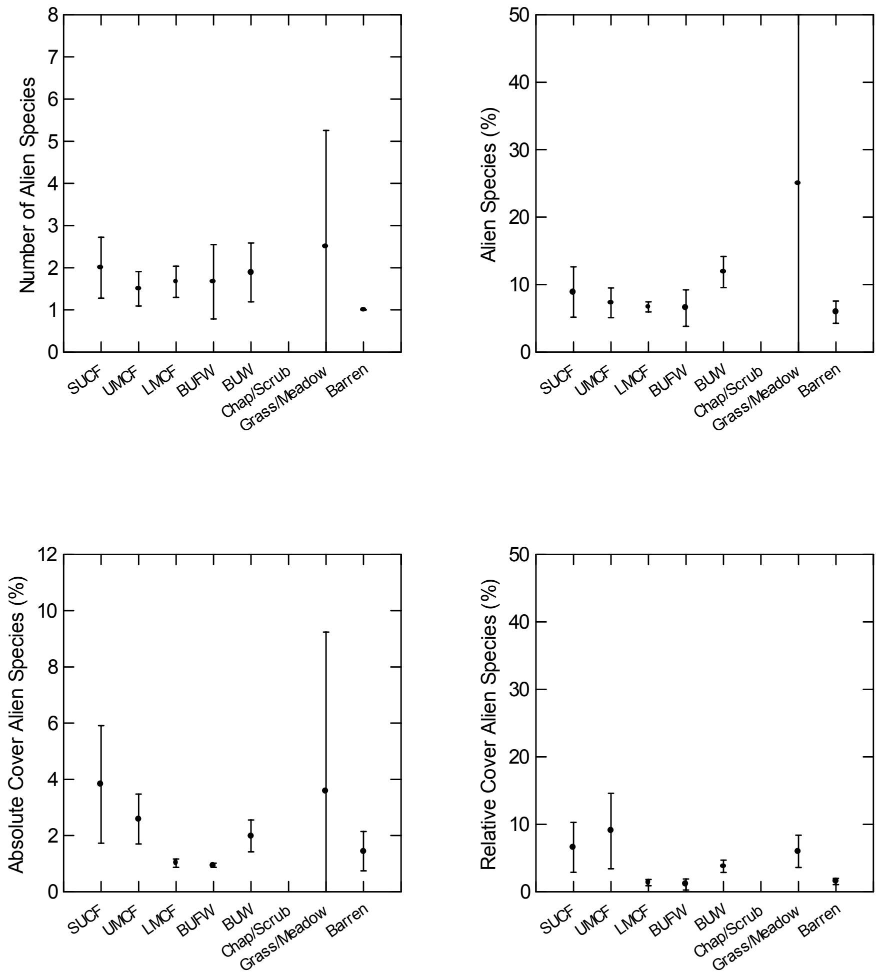


Figure 3. Species richness and abundance (% cover) of alien species in vegetation formations in Yosemite National Park, California. The data are from NRI plots sampled from 1989 – 1993.

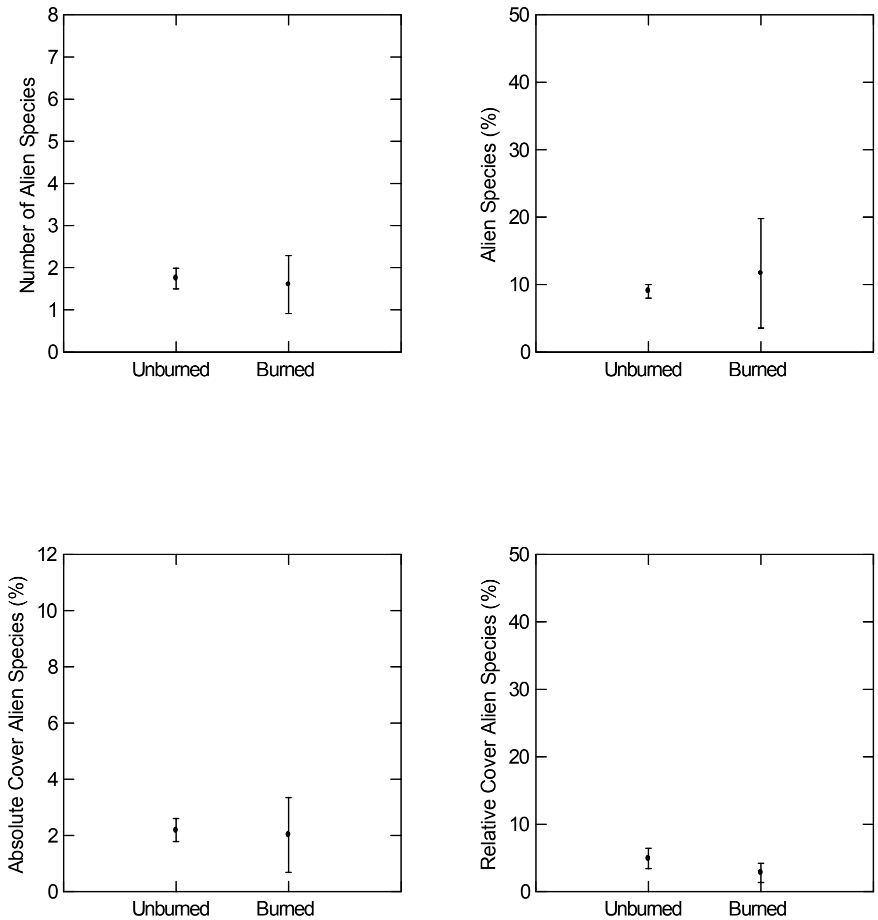


Figure 4. Species richness and abundance (% cover) of alien species in burned and unburned plots in Yosemite National Park, California. The data are from NRI plots sampled from 1989 – 1993.

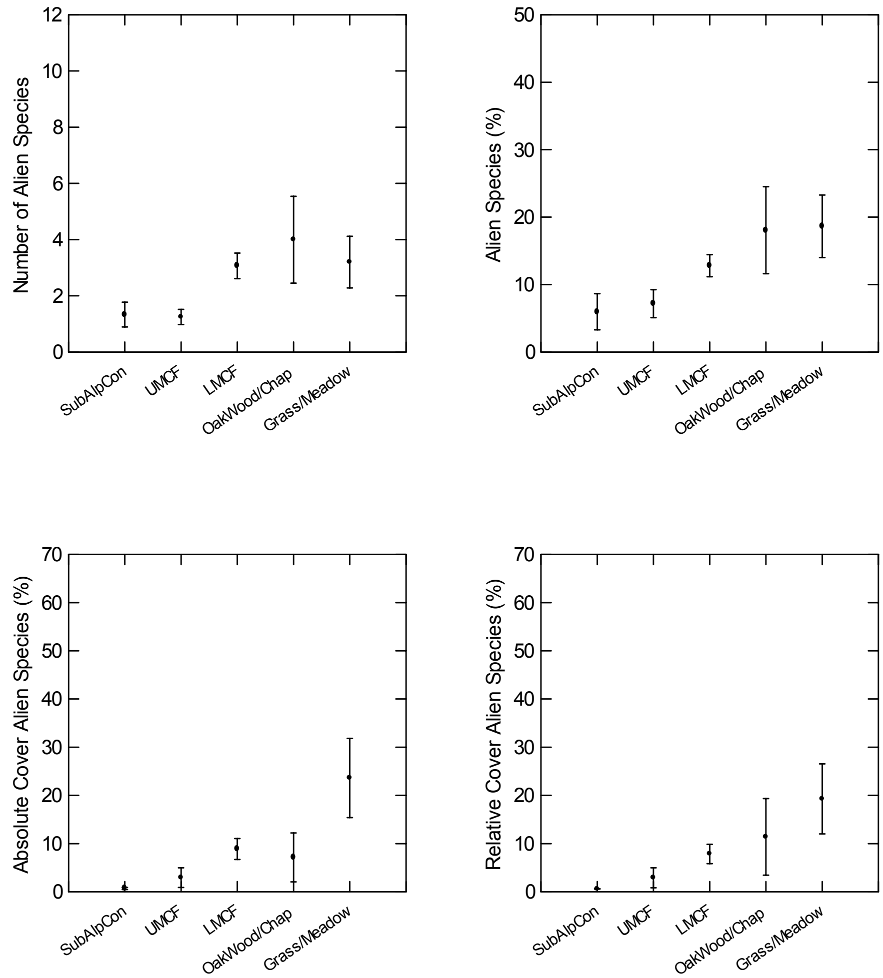


Figure 5. Species richness and abundance (% cover) of alien species in different vegetation formations at Yosemite National Park, California. The data are for TNC plots sampled in 1998 and 1999.

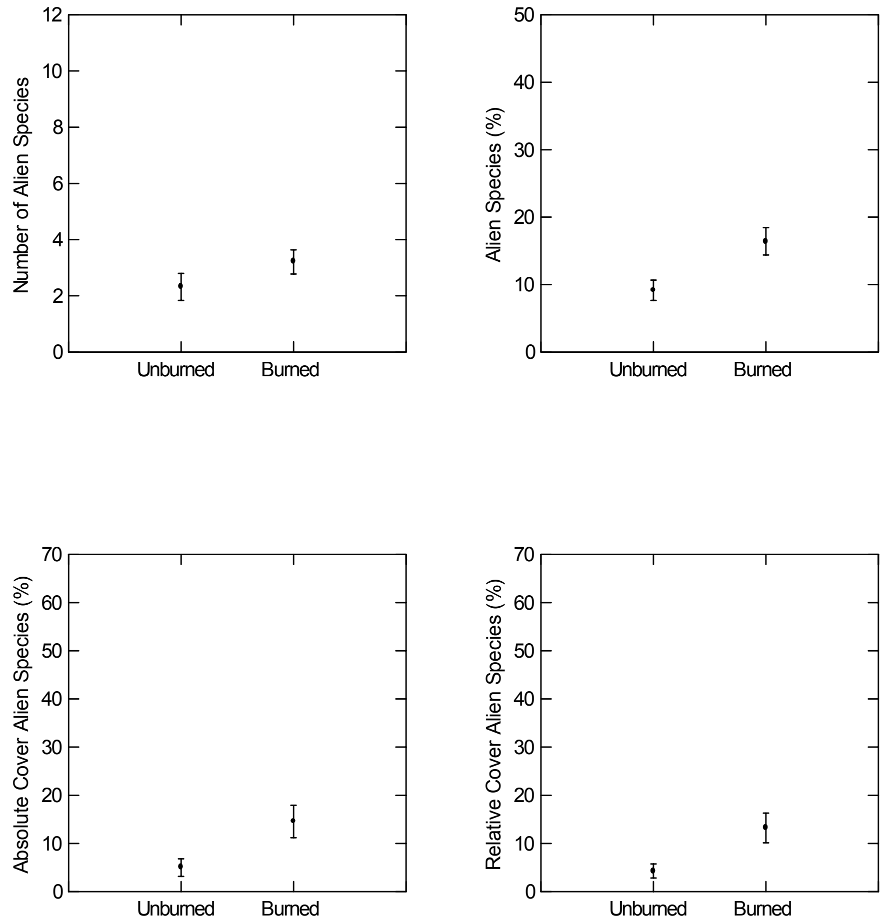


Figure 6. Richness and cover of alien species in burned and unburned plots at Yosemite National Park, California. The data are for TNC plots.

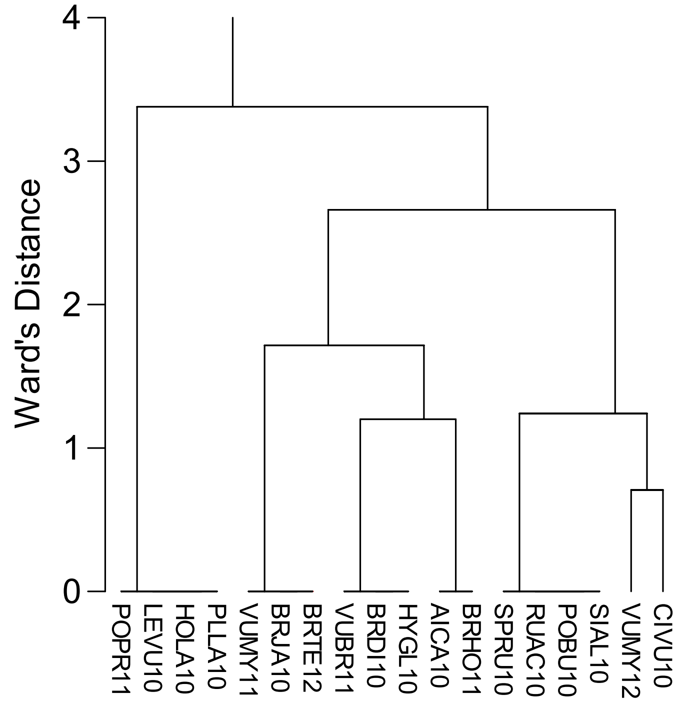


Figure 7. Dendrogram of species associations based on a TWINSPAN analysis of 18 alien species in 36 NRI plots in Yosemite National Park, California.

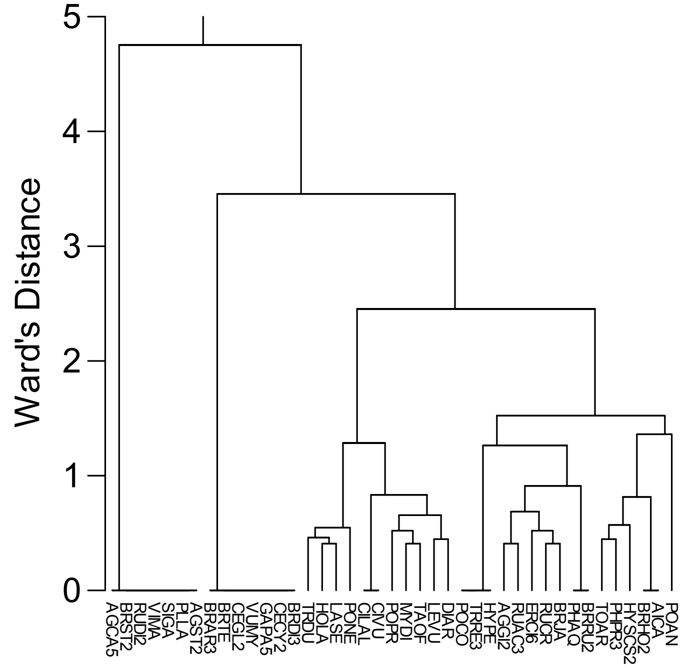


Figure 8. Dendrogram of species associations based on a TWINSPAN analysis of 41 alien species in 57 TNC plots in Yosemite National Park, California.

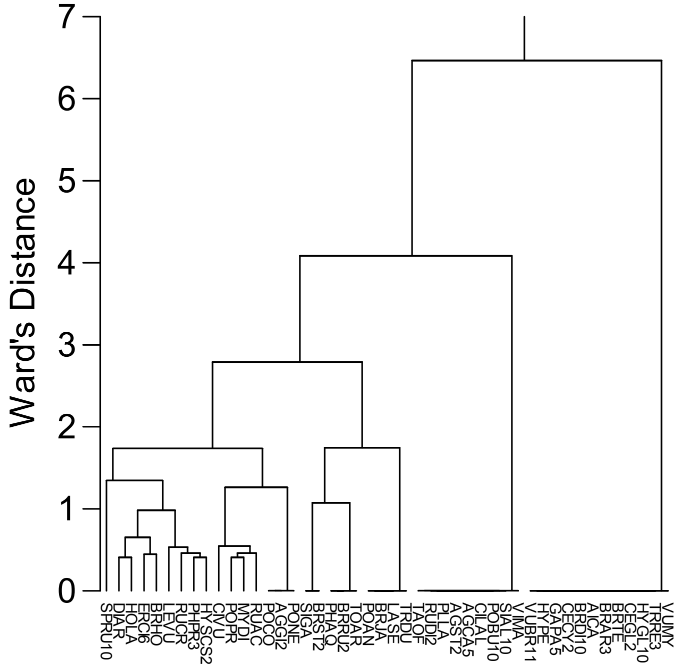


Figure 9. Dendrogram of species associations based on a TWINSPAN analysis of 46 alien species in 93 NRI and TNC plots in Yosemite National Park, California.

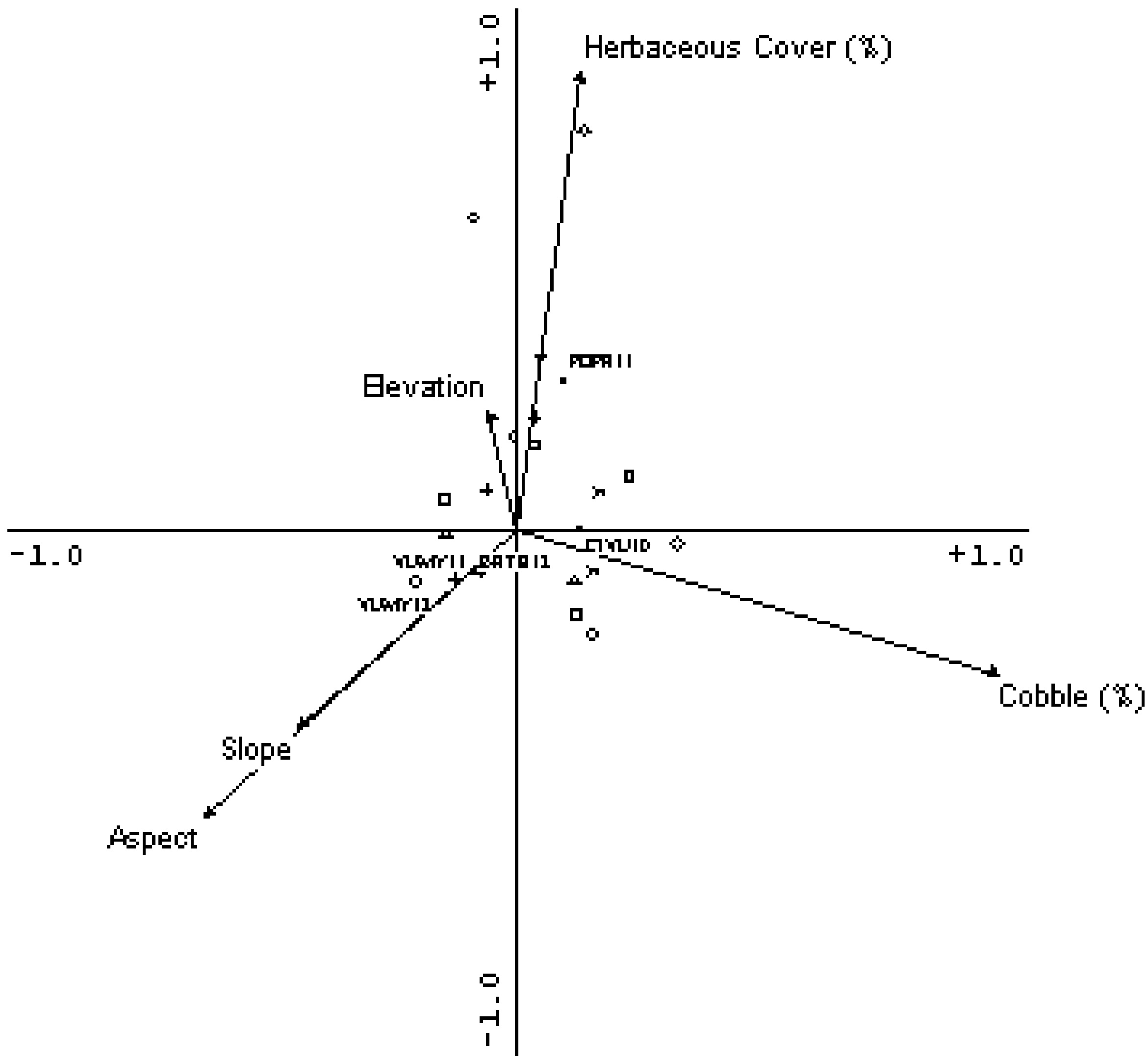


Figure 10. Canonical Correspondence Analysis biplot of the first two ordination axes for 36 NRI plots where alien species (N=18) were present in Yosemite National Park, California. The ordination was based on cover values for just the alien species. Vegetation formation symbols are: * = chaparral/scrub, + = broadleaf woodland, open squares = upper montane conifer forest, open circle = lower montane conifer forest, open diamond = grassland/meadow, open up-pointing triangles = subalpine conifer forest.

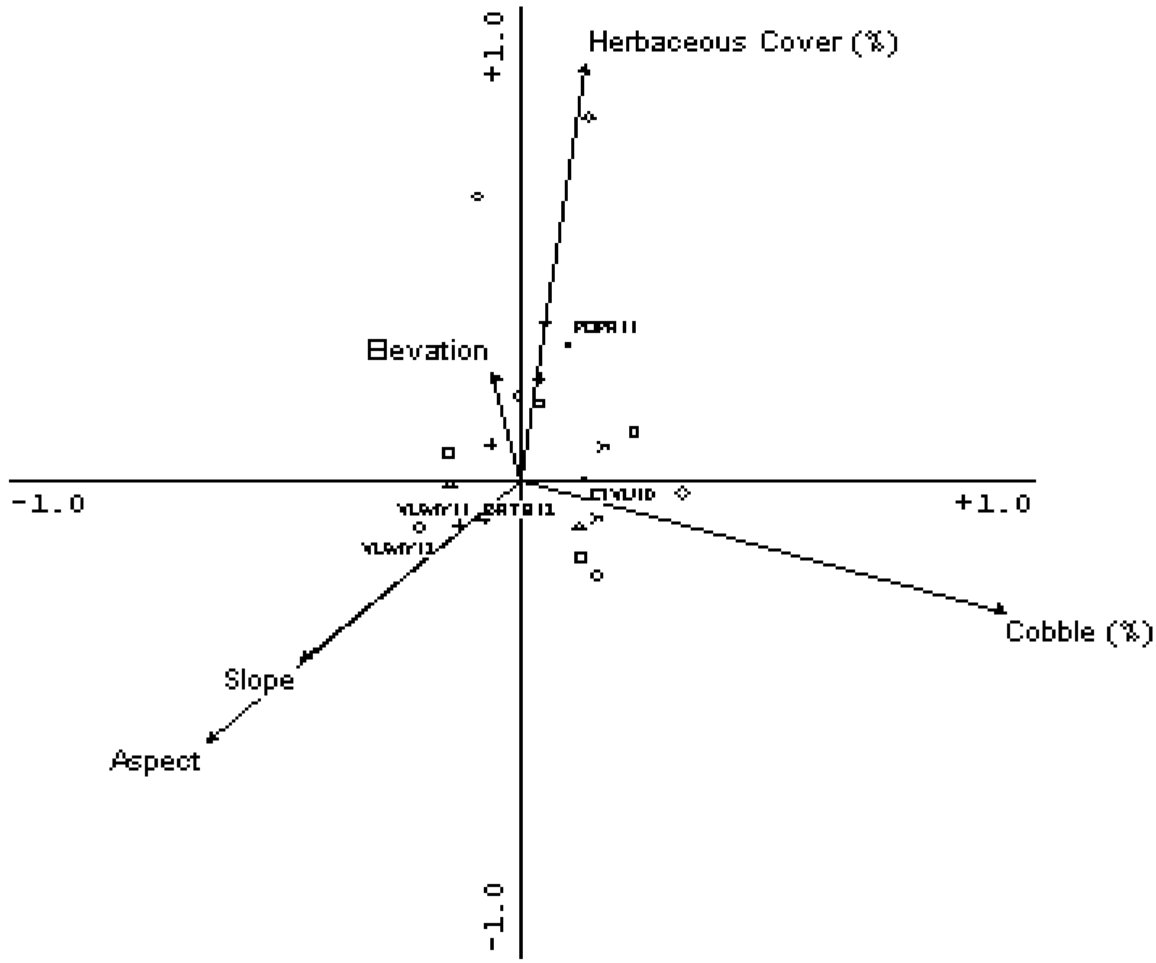


Figure 11. Canonical Correspondence Analysis biplot of the first two ordination axes for 57 TNC plots where alien species (N=41) were present in Yosemite National Park, California. The ordination was based on cover values for just the alien species. Vegetation formation symbols are: * = chaparral/scrub, + = broadleaf woodland, open squares = upper montane conifer forest, open circle = lower montane conifer forest, open diamond = grassland/meadow, open up-pointing triangles = subalpine conifer forest.

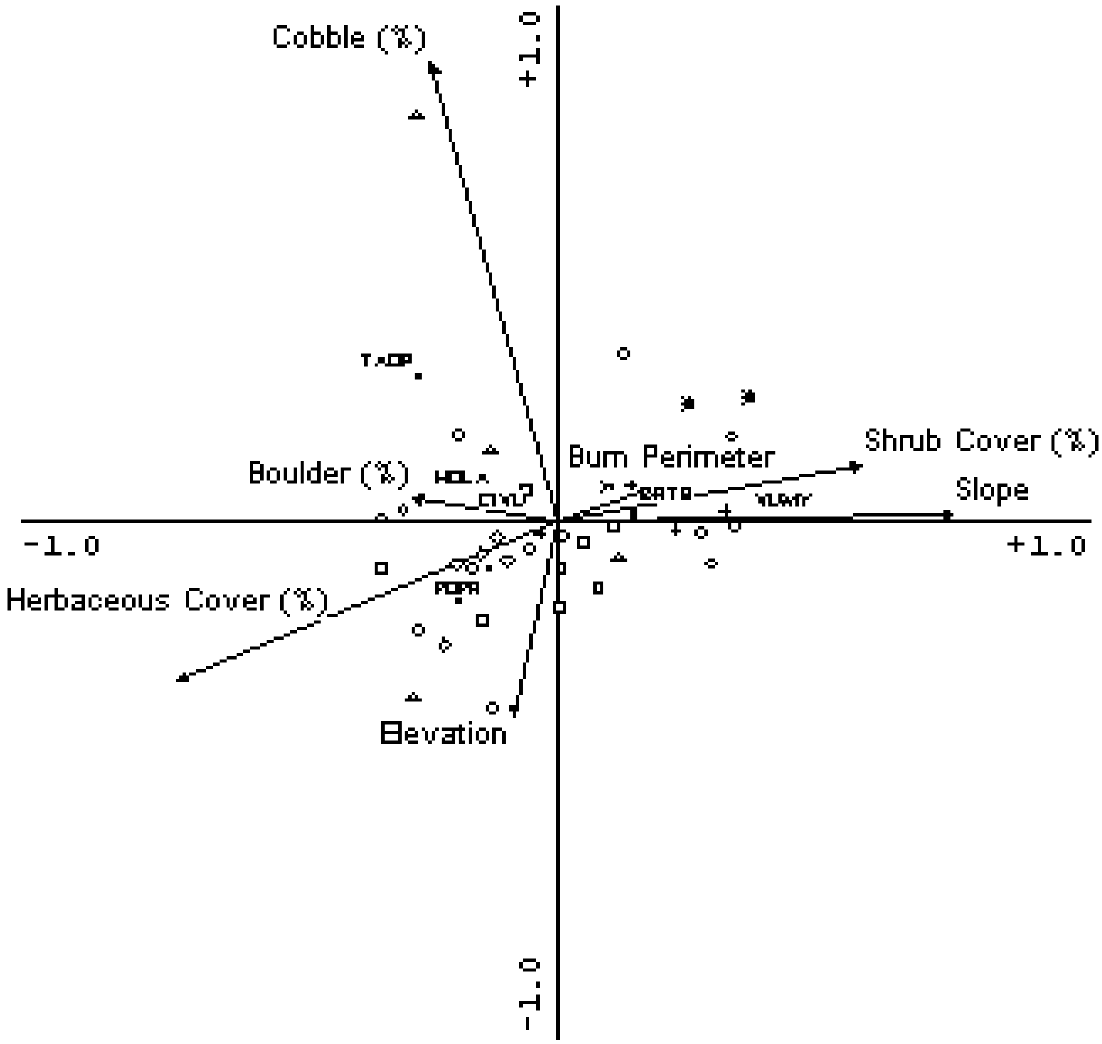


Figure 12. Canonical Correspondence Analysis biplot of the first two ordination axes for 93 NRI and TNC plots where alien species (N=46) were present in Yosemite National Park, California. The ordination was based on cover values for just the alien species. Vegetation formation symbols are: * = chaparral/scrub, + = broadleaf woodland, open squares = upper montane conifer forest, open circle = lower montane conifer forest, open diamond = grassland/meadow, open up-pointing triangles = subalpine conifer forest.

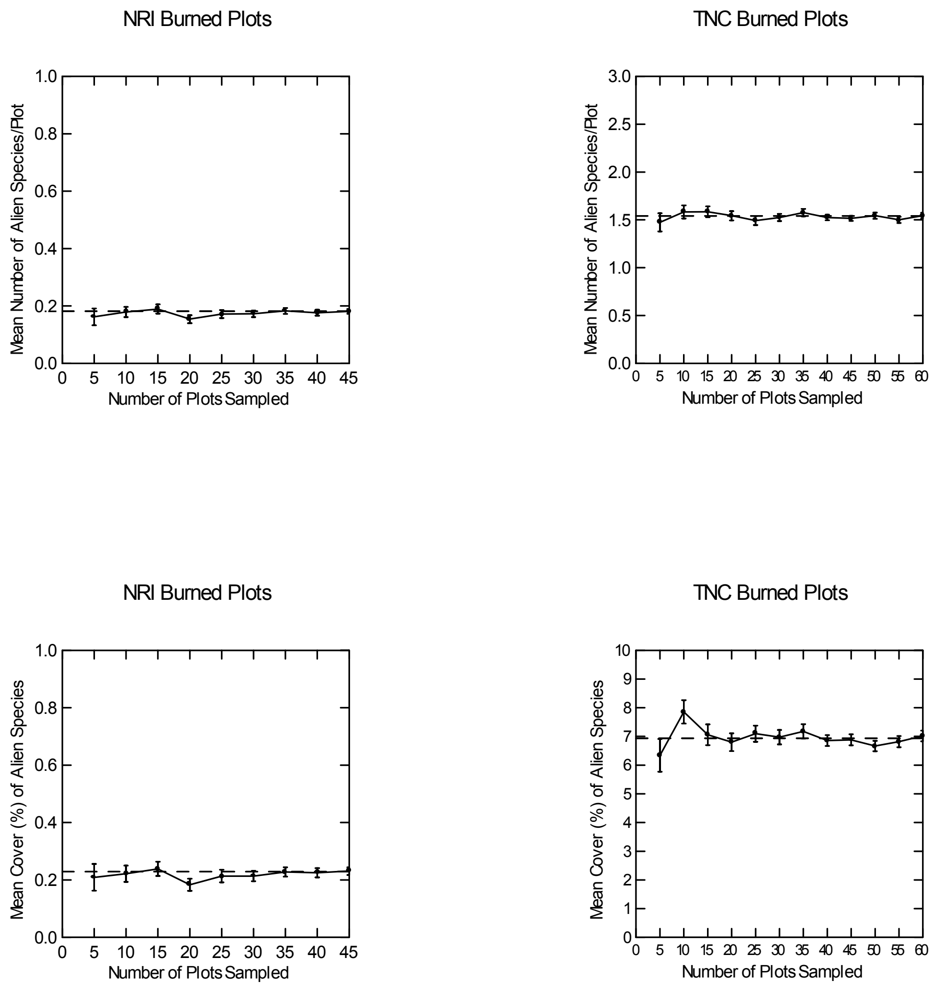


Figure 13. Bootstrapped values of the mean number and percent cover of alien species/plot in 45 NRI and 62 TNC burned plots in Yosemite National Park, California. Bootstrapped values in the NRI data set were based on 100 random selections for sample sizes (number of plots) of 5, 10, 15, 20, 25, 30, 35, 40, and 45. Bootstrapped values in the NRI data set were based on 100 random selections for sample sizes of 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55 and 60. Limit lines on the y-axis are for the empirically calculated means of number of species and cover. Error lines are $\pm$ one standard error of the bootstrapped mean.

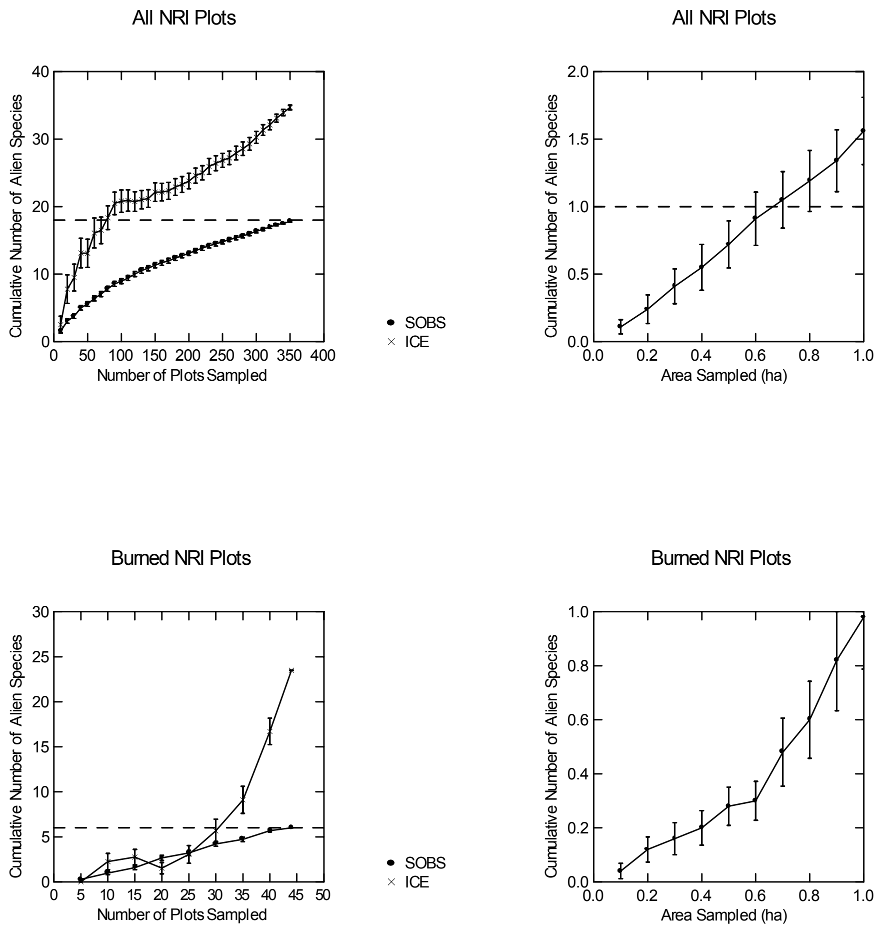


Figure 14. Bootstrapped values of the total number of alien species/plot observed (SOBS), the total number estimated to occur (ICE), and the mean cumulative number of alien species/unit area in NRI plots at Yosemite National Park, California. There were a total of 356 unburned and 45 burned plots. Bootstrapped values for the number of plots were based on 100 random selections for sample sizes ranging from 1 – 350 in the unburned plots and 1 – 45 in the burned plots. Bootstrapped values for the number of species/unit area were also based on 100 random selections for sample sizes ranging from 0.1 – 1.0 ha. The limit line on the y-axis is for the observed total number of species in the plots. Error lines are ± one standard error of the bootstrapped mean.

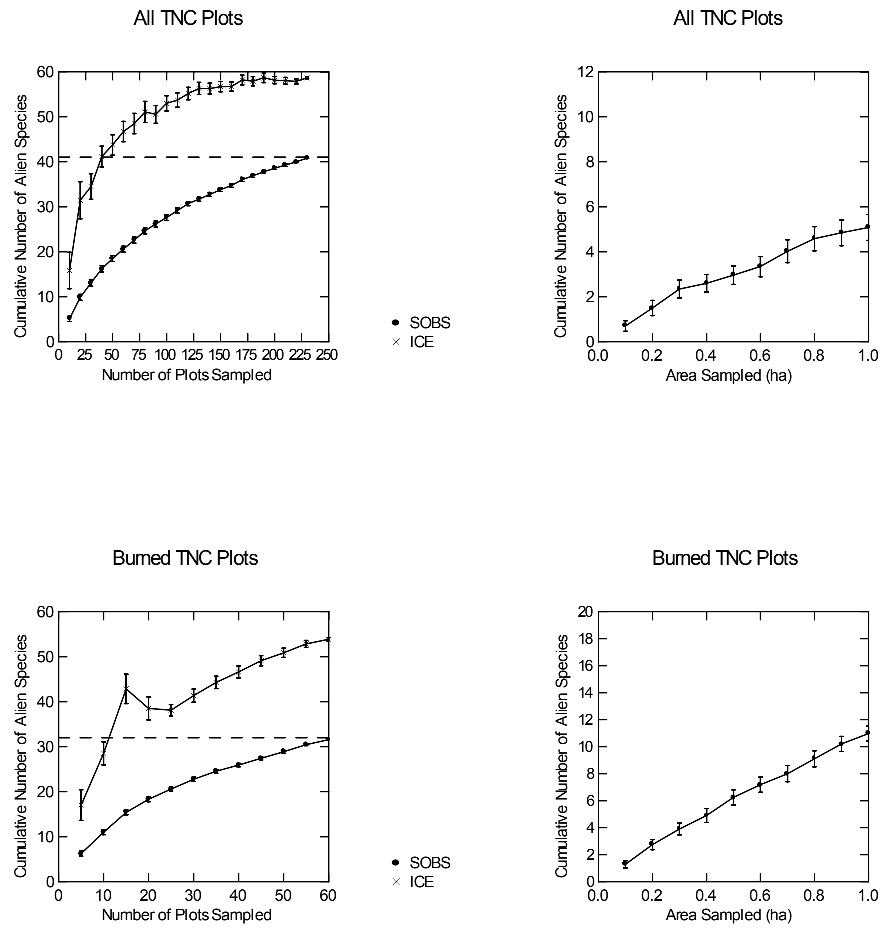
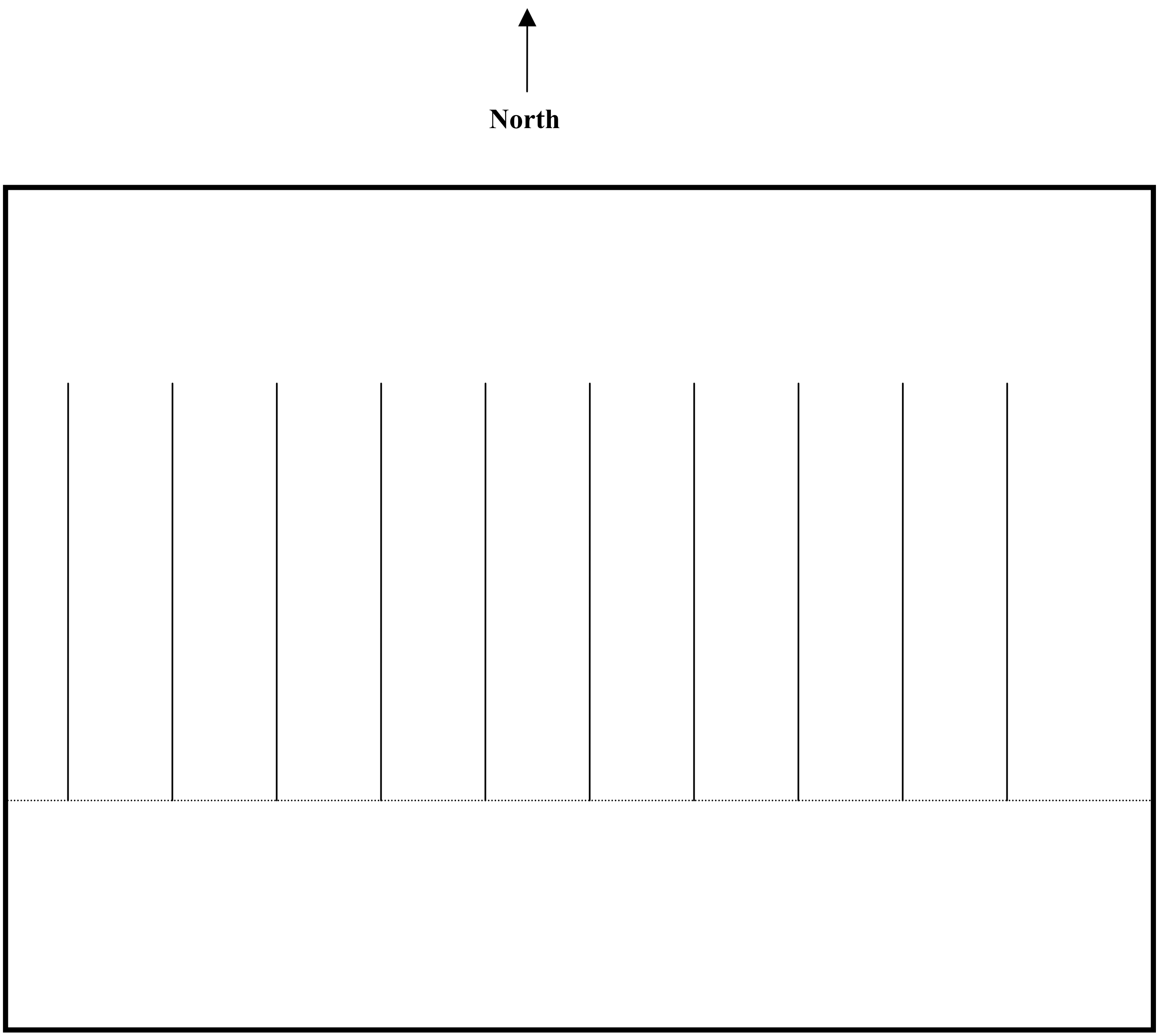


Figure 15. Bootstrapped values of the total number of alien species/plot observed (SOBS), the total number estimated to occur (ICE), and the mean estimated cumulative number of alien species/unit area in TNC plots at Yosemite National Park, California. There were a total of 236 unburned and 62 burned plots. Bootstrapped values for the number of plots were based on 100 random selections for sample sizes ranging from 1 – 235 in the unburned plots and 1 – 60 in the burned plots. Bootstrapped values for the number of species/unit area were also based on 100 random selections for sample sizes ranging from 0.1 – 1.0 ha. The limit line on the y-axis is for the observed total number of species in the plots. Error lines are $\pm$ one standard error of the bootstrapped mean.

Appendix 1. Example of a 1.0 ha plot for inventorying alien plants in burned areas in Yosemite National Park, California. The west side is the primary side of the plot, the east side the secondary side of the plot, the dashed line is the baseline where ten 50m x 2m transects originate, and the thin lines running north from the baseline are the transects. The baseline extends between the 35m marks on the primary and secondary sides. The transects began at the 11m mark along the baseline. The beginning of the baseline and transects were selected randomly.



Appendix 2. Example of a field data sheet used for inventorying alien plants in burned areas of Yosemite National Park, California.

Plot ____________

Primary Side ___________________

Baseline Meter Mark ____________

UTM Coordinates _____________________

Burn Name ____________________

Vegetation Alliance ____________________

Date ________________________

Crew Members _______________________

Transect Number (1 – 10): ________

Transect Starting Meter Mark ____________

	Cover Class (Daubenmire Values)							
Species Code	0	1 (< 1.0%)	2 (1-5%)	3 (5-25%)	4 (25-50%)	5 (50-75%)	6 (75-95%)	7 (>95%)

Instructions: Enter the code for each species in the 1.0 ha plot. Put a tick mark in one of the cover class boxes for each subplot. There should be 25 tick marks for each species. Circle the species codes for species that were found in the plot but did not occur in the subplots.

Appendix 3. Example of a field data sheet used for inventorying alien plants in riparian areas of Yosemite National Park, California.

Plot ____________ Name of Watercourse __________________

UTM Coordinates ____

Date ________________________ Crew Members ________________________

Side of Watercourse _________________________

	Segment of Watercourse									
Species Code	1	2	3	4	5	6	7	8	9	10

Instructions: List all species observed in the plot. Segments are 100m subsections of the entire plot. Enter a 0 (not present) or a 1 (present) in each segment for each species.

SECTION II: DESCRIPTION OF GIS METHODOLOGY AND PREDICTIVE MODELING

The objectives of the GIS component of the project were twofold:

1. To attribute the plot data with spatial attributes for community scale analyses
2. To develop predicted, or probability landscapes, for groups of alien species using the findings from the analyses of the plot data

All GIS analyses were conducted using Arcview v.3.2 and ArcInfo v.8.1. The predictive modeling was conducted using a program called the Genetic Algorithm for Rule-set Prediction (GARP) developed by David Stockwell at the San Diego Supercomputer Center (http://biodi.sdsc.edu).

A. ATTRIBUTING TNC AND NRI DATA SETS WITH SPATIAL INFORMATION

The TNC 1999, 1998, and NRI plots were imported into the GIS using the coordinates provided in the Access database (Figure 16). The projection of all GIS analyses was UTM zone 11 and, unless specified, the gridcell size was 30 m. The first step was to stratify all plots into 'burn', 'riparian' or neither, followed by attributing the plots with both environmental and anthropogenic variables.

A.1. Categorizing Burn and Riparian Plots

(i) Burn plots were identified simply by performing a spatial join on the fire history dataset (FH1930_2000.shp). Any of the TNC98, TNC99, and NRI plots falling within these delineations were coded by the size, type, cause, decade, and number of burns. Where plots were located in areas where more than one burn had occurred plots were labeled with the attributes of the most recent burn.

(ii) Riparian plots were categorized using two approaches. First, streams were buffered on either side by 30 m and second, riparian related vegetation was selected from the 1937 vegetation map (vtm_1982.shp). These included the following classes:

- Alpine/subalpine meadows
- Boggy meadows
- Lodgepole pine meadows
- Low elevation meadows

Any plots that fell within these polygons or the stream buffer were categorized as riparian. We felt that using only one approach would result in missed riparian plots; for example, only 17 plots from the TNC99 data fell into the stream buffer zone but a further 44 plots were captured using the riparian vegetation polygons. A comparison of riparian areas was also made using the 1937 vegetation map by selecting for dominant riparian species (in categories W1, W2, W3, or W4): such as *Salix*, *Populus*, *Acer*, *Betula*, or *Alnus*. We felt that these selected regions captured too small a spatial area, were not necessarily very close to rivers, and underrepresented riparian areas in lower elevations, which is where the majority of the plots are located.

A.2. Assigning Plots with Spatial Information

The spatial information assigned to each plot was based on data contained within the Yosemite GIS as well as data sets derived specifically for this project. All plots were attributed using either a spatial join for vector data or assigning the gridcell value to the plot for raster data. Table 13 summarizes the data layers used.

Table 13. Available data layers for Yosemite National Park, California.

Data type	Format	Units	Resolution	Source
Environmental data				
Elevation	Grid	meters	30 m	Yosemite GIS
Slope	Grid	degree	30 m	Yosemite GIS
Aspect	Grid	degree	30 m	Yosemite GIS
Fire Return Interval (med and max)	Grid	NPS code	30 m	Yosemite GIS
Fuel Model	Grid	NPS code	30 m	Yosemite GIS
Vegetation alliance	Vector	classes	MMU 15-25 acres	1937 vegetation map
Vegetation formation	Vector	classes	MMU 15-25 acres	1937 vegetation map
Distance to streams	Grid	Meters	10 m	Derived from streams
Stream order	Grid	1 – 7	30 m	Derived from elevation
Soil composition	Vector	percent	1:250,000	Derived from STATSGO
Anthropogenic data				
Distance to campgrounds	Grid	meters	10 m	Derived from campgrounds layer
Distance to trails	Grid	meters	10 m	Derived from trails layer
Distance to road	Grid	meters	10 m	Derived from roads

A.3. Description of Derived Data Layers

(i) Soils

The soils data were derived from the State Soil Geographic (STATSGO) data base which was developed by the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service. The STATSGO data layer was projected from Teale Albers to UTM zone 11 and clipped to the boundary of the park. Since this is a statewide coverage the resolution for the park is extremely coarse – with only 37 polygons falling within the park boundary (Figure 17). From this dataset the percent stone, sand, silt, clay, loam, cobble, gravel, and boulder were calculated for each polygon. We also looked at the ‘bedrock’ attribute in the coverage to assess if it would be useful for assigning riparian areas, but found little differentiation of bedrock values within the park.

(ii) Stream order

Although there is a stream layer in the Yosemite GIS, the standard method for calculating stream order is conducted using a Digital Elevation Model (DEM). The DEM (30 m resolution) was corrected for any spurious sinks and peaks in the data, and then a series of commands performed using ArcInfo Grid. First, the ‘flow direction’ was calculated for the DEM, which is determined by finding the direction of steepest descent from each cell:

$$\text{drop} = \text{change in z value} / \text{distance} * 100$$

Second, the ‘flow accumulation’ was determined to define the amount of upstream area draining into each cell – i.e.: essentially a measure of the upstream catchment area. Third, a stream network was created by selecting cells with a threshold level of accumulated flow. This threshold was determined by using the recommended 100 cells (ArcInfo manual) visually comparing this to the vector coverage of streams, and iteratively increasing this level to improve the match, finally settling on a threshold level of 150 cells. The stream network created using the DEM reflected the vector coverage fairly well although a number of additional streams were identified (Figure 18). This is likely to be caused by the scale of the DEM. A 10 m DEM would produce much better results, or conversely, this method might have successfully identified smaller streams that do exist but were not digitized into the stream coverage. The final step was to calculate stream order with this derived stream network, using the Strahler method (the most frequent approach). In this approach stream order only increases when streams of the same order intersect; thus the intersection of a first order and second order link will remain a second order link rather than create a third order link.

Investigations were made into deriving stream gradient information. A web search and discussions with other GIS experts showed no readily available Arcview script or ArcInfo aml - consequently, it would have been very time intensive to calculate manually. Also, we did not feel that it was urgent, since none of the stream related attributes (distance to stream, stream order) were appearing as significant in the regression analyses.

(iii) Anthropogenic data layers

Most of the park campgrounds were provided in the Yosemite GIS but three additional areas (Yellow Pine, former Upper and Lower River, North Pines and Upper Pines, and Campground 4) were digitized to complete the coverage. This was done by digitizing a 50 m buffer around any roads labeled ‘campground road’ in the road shapefile. The calculation of distances from roads and trails also included any that were outside of the park, as these obviously still influence plots located at the boundary.

B. PREDICTING THE PROBABILITY OF ALIEN COVER IN YOSEMITE

Spatial analyses and modeling using GIS is particularly well suited for extrapolating from the site characteristics of a particular species, or group of species, to identify other areas in the landscape that share these conditions. Analysis of landscape features such as elevation, slope, soils, vegetation type, and proximity to areas of human activities (e.g. roads, campgrounds) can give a better ecological context to the distribution patterns and species associations than plot-based data alone. Correlating the geographic location of alien species from the TNC98/99 and NRI/TNC plot data with the available data layers, allows us to identify the environmental or disturbance niches of the alien species.

B.1. Methodology

The community scale analyses provide two critical pieces of information for the predictive model. The TWINSPAN analysis grouped similar species together, which meant modeling could be undertaken more efficiently than on a species by species basis. The Canonical Correspondence Analysis (CCA) identified the principle environmental or anthropogenic data layers that were related to each plot and could then be used as inputs into the model.

Two approaches were used for predicting the potential distribution of the groups of alien species. First, manually selecting from the GIS the range of environmental and anthropogenic gradients as identified by the CCA. Second, using the plots of the grouped species as training, or input, data (as oppose to verification plots) in a predictive model. The major advantage of using the GARP model is that more sophisticated predictions can be made about potential locations of alien species based on the combination of input data layers. Two predictive models were performed on each of the two data sets: the first using environmental layers as input data to identify the environmental envelope of the different species groups and second, using anthropogenic data layers to highlight areas of potential alien species which might be caused by disturbance factors.

i. Predicted Distribution Based on Manual Selection of Data Layers

While the environmental and anthropogenic gradients associated with each species within species group could be picked out individually, e.g. all gridcells with a slope of 25^{o} and an elevation for 1556 m (BRTE record for plot TNC99K46) this would result in only a fraction of the spatial area of the park being selected. Consequently, the approach conducted was to select all gridcells encompassed by the range of values for each data layer within the species group (Table 14).

Table 14. Range of environmental data layers for TNC98/99 species group.

Data layer	Species Grp.1	Species Grp. 2	Species Grp. 3	Species Grp. 4
Elevation (m)	1212-1576	1187-1576	855-2924	1182 – 2924
Slope (degree)	3 – 25	1 - 28	1 – 11	1 - 13
Veg. Alliance	C1	C1	A2	A2
	C5	C3	B4	B1
	F2	D1	C1	B4
	G2	H2	C4	C1
	H2	I1	C5	C4
	I1		D1	C5
			H2	D1
			I1	H2
				I1

However, once the range for each of the environmental and anthropogenic data layers was chosen and combined, only a small portion of the park was left unselected. We felt that this potential landscape was too broad to be useful for refining the choice of sites for sampling. Given the greater variability of data layers from the NRI/TNC plots this effect would have been even more exaggerated than for the TNC98/99 plots and so this method of determining predicted distribution of aliens was not undertaken.

ii. Using the GARP Predictive Model

The Genetic Algorithm for Rule-set Prediction (GARP) model was developed by David Stockwell at the San Diego Supercomputer Center. Previous studies using GARP have reported it to be a superior technique for predicting potential species distributions (Godown, 2000). This is largely because it incorporates a number of different algorithms - such as BIOCLIM (Nix, 1986) and logistic regression techniques - consequently overriding the disadvantages of using each method individually. For example, problems can often be encountered when using a large number of environmental data layers or using categorical information (see Godown 2000 for a full critique). GARP works by iteratively processing rules from a set of four: atomic, range, negated range rules and logistic regression, which are then evaluated with respect to the input species distribution data. These rules are then either rejected or incorporated based on a sampling of the species data compared to a similar number of points selected randomly from the study region (Stockwell and Noble, 1991). In essence, the geographic locations of plots containing alien species cover are specified and then correlated against the environmental and anthropogenic data layer grids.

Preparation of Environmental and Anthropogenic Data Layers

The key data layers that tended to have the most important relation to the distribution and abundance patterns of alien species are listed in Table 15. Selection of these layers was based on the results of the regression and CCA analyses. For the TNC98/TNC99 plots only three environmental data sets were used as input data for the predictive model, while the NRI/TNC mixed plots had five. The community analyses identified the percent tree and shrub cover as consistently significant variables. In the absence of any data layers pertaining specifically to these, vegetation alliance and formation data from the vegetation map was used as a surrogate. Comparisons were made between the results of predictions using vegetation alliance versus vegetation formation to decide which to use - the predictions using alliance data being consistently more accurate. Where necessary the data were converted into grid format (30 m resolution) and then all layers exported to an ASCII file format in preparation for running the GARP model.

Table 15. Input data for predictive model (Y = yes).

Input data layers	TNC98/99	NRI & TNC98/99
Environmental prediction		
Elevation	Y	Y
Slope	Y	Y
% tree & shrub cover (vegetation alliance)	Y	Y
% boulder		Y
Distance from streams	Y	Y
Anthropogenic prediction		
Distance from roads	Y	Y
Distance from trails	Y	Y

Selection of TNC98/99 and NRI/TNC Input Plots for Predictive Model

Using the results of the TWINSPAN and CCA plots within each species group were sorted by plot number then descending percent alien cover. Within each species group some plots were listed for more than one species. In this event, the record with the highest amount of alien cover was selected, since the model requires each input record to be unique in terms of geographic location. For example, there were 163 plots in the four species groups of the TNC98/99 data set however this was reduced to 93 once records of duplicated plots – albeit with a different species code - were removed. The unique plots within each species group were sorted by percent alien cover and the highest 80% were coded as training plots (a minimum of ten is needed to run GARP) leaving 20% to be used for verification of the prediction results (Table 16). This data were imported into Arcview using the plot UTM coordinates and separate shapefiles generated for each of the species groups in both the TNC98/TNC99 data and the NRI/TNC data.

One key point to emphasize is that plots between species groups were not necessarily unique, for example, one plot (TNC98K26) was selected for species group one because it had 3% *Bromus tectorum* cover, however, the same plot was selected for species group four as it also has a high cover of *Cirsium Vulgare*. Ideally unique plots for each species groups would allow us to say definitively how one group is responding to the environmental and anthropogenic data layers.

Table 16. TNC98/99 and NRI/TNC plots.

TNC98/99 plots: 93 unique plots (out of 163)

Sp. Group	Unique plots	Input plots	Verification plots
1	15	11	3
2	18	14	4
3	28	24	4
4	32	26	6

TNC/NRI: plots: 117 unique plots (out of 225)

Sp. Group	Unique plots	Input plots	Verification plots
1	47	38	9
2	25	20	5
3	45	36	9

The predictive model was then run on the training plot shapefiles for each of the seven species groups using the appropriate data layers. For each of the species groups the rule sets are run for 1000 iterations each, using 50% of the input data for training and the remainder for validating each rule, for a total of 20 times. In short, fourteen different predictive models were run: four environmental and four anthropogenic for each of the species groups in the TNC98/TNC99 plots, and three environmental and three anthropogenic for each of the species in the NRI/TNC plots.

When the processing had finished (approximately 40 minutes for each model) the results were converted from ASCII file format into ArcInfo grid format, the mean of each of the 20 runs calculated and then imported into Arcview. Our final probability surface of alien invasions was derived by combining the results of the environmental and anthropogenic models. However, after visually inspecting the predictions based on anthropogenic factors we decided to reduce their importance by only selecting locations which had a probability of 75% or higher. This is because the environmental limitations on the species group are likely to override these anthropogenic effects. For example, even though species group one is predicted to occur eastwards along Tioga Road, it probably will not since it is limited in the elevation that the species group can tolerate.

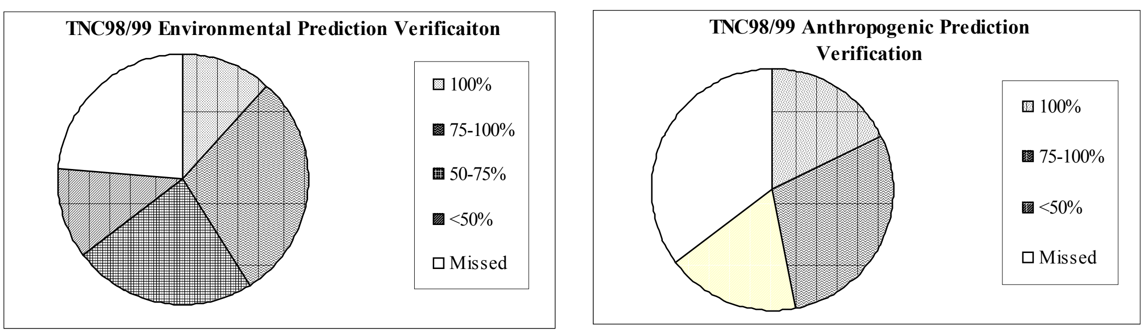
B.2. Results

i. Results of GARP for TNC98/99 Plots

The results from the predictive models are shown in Table 17. The 'env_prob' and 'anth_prob' columns show the respective results using the environmental and anthropogenic layers. The 'status' column indicates whether the plot was used as input data on which the model is trained or reserved for verification of the model results. The values range from 0-1. One implies that that particular gridcell (30 m x 30 m) has the highest probability (100%) of an occurrence for that species group: i.e.: it contains a combination of environmental or anthropogenic data layers most similar to that of the input plots, while a value of zero means that it has no probability.

The model results can be assessed by looking at the probability of the verification plots: ideally we want this to be as high as possible, since we know definitively from the database that these plots do harbor alien species.

Figure 19. Accuracy assessment of predictive model for TNC98/99 plots.



In the above graphs (Figure 19) both the environmental and anthropogenic models did predict a proportion of the plot locations with 100% accuracy, and also a notable number with higher than 75% probability. It is also interesting to note the proportion of missed plots and some explanations for this are in the discussion section below. However, in the case of the anthropogenic data, it might well be because there were no strong patterns found in the plot data, reflecting the findings of the regression analyses; that while there was no significant relationship with distance from roads or campgrounds, there was in fact, a positive correlation with trails for the TNC data.

The results from the predictive modeling based on the environmental, anthropogenic and their combined values are depicted in the maps shown in Figures 20-42: points in purple are the plots used as inputs for the model, while points in red are plots reserved for verification purposes.

TNC98/99 Species Group 1

The predicted patterns based on the environmental data layers for species group one (which includes *Bromus Tectorum* and *Vulpia myuros*) appears to be largely driven by elevation (Figure 20). Cross reference with the DEM show that these species are predicted to occur on areas less than 1600 m which explains the regions of high predicted probability in four concentrations along the western boundary of the park and eastward following the Tuolumne and Merced Rivers. This is also reflected in the literature on these species (TNC Stewardship Abstracts http://tncweeds.ucdavis.edu/esadocs.html and US Forest Service http://www.fs.fed.us/database/feis/plants). The predicted distribution of this group using the anthropogenic data layers shows a large influence of the road network; particularly along Tioga Road reaching eastwards into the higher elevations and also eastwards along the Yosemite Valley (Figure 21). The combined total of all areas predicted to have any degree of probability by the environmental prediction with the 75-100% probability areas from the anthropogenic layers reflect the elevation driven patterns seen before, with the addition of a number of high probability patches occurring along key roads (Figure 22).

TNC98/99 Species Group 2

Species group two is dominated by *Holcus lanatus* and *Lactuca serriola*. Their predicted distribution is somewhat similar to that of species group one, although more severely restricted to the Tuolumne, Merced, and South Fork of the Merced River (Figure 23). The distribution patterns also strongly follow the ponderosa pine (C1 and C3) and foothill pine-live oak-chaparral woodland (F2) alliances in the vegetation data. The preference for flat, slopeless areas reported in the literature (US Forest Service) can also be depicted. The results based on the anthropogenic data layers is dominated by the distance from roads, and the majority of Tioga Road, the Yosemite Valley and Glacier Point Road have a high probability (Figure 24). Even when selecting the top 75% of anthropogenically determined areas, the combined result of the two data sets still has a significant amount of roadside areas that are predicted as harboring alien species (Figure 25).

TNC98/99 Species Group 3

The main species in this group are *Phleum pretense* and *Hypericum scouleri*. The prediction based on the environmental data layers shows this species group to be tolerant of a broader range of elevation conditions than seen in species groups one and two, reaching to 2200 m (Figure 26). Interestingly, the plot (TNC99S138) on the far eastern side of the park was not close to any predicted area of distribution, which could suggest that this might be a spurious record of alien cover. The anthropogenic based predictions show a similar pattern to species group two and four, with distance from road dominating (Figure 27). The combined grid of the predicted results shows a broad area to sample in the western third of the park (Figure 28).

TNC98/99 Species Group 4

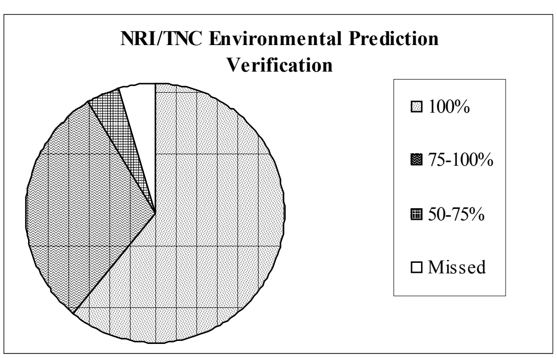
The dominant species of group four are *Poa pratensis* and *Cirsium vulgare, which* have a much wider predicted distribution than for the previous species groups. This species group is predicted to be widely distributed in areas less than 2700 m in elevation, while at the same time avoiding steeply sloping terrain (approximate > 13^{o}) (Figure 29). The sweeping spatial distribution of this group suggests that vegetation alliance is not a driving force. Such patterns again reflect the literature on these species – *P. pratensis* characterizes numerous vegetation types of moderate to high elevations, while *C. vulgare* can tolerate dry to moist habitats and does poorly on steep slopes. The prediction using the anthropogenic layers yields a similar pattern to that of species group two and three: distance to roads the primary influence, distance to campgrounds less so, and no visible contribution of the distance to trails (Figure 30). A combination of the two predictions gives the widest probability landscape of any of the TNC98/99 species groups (Figure 31).

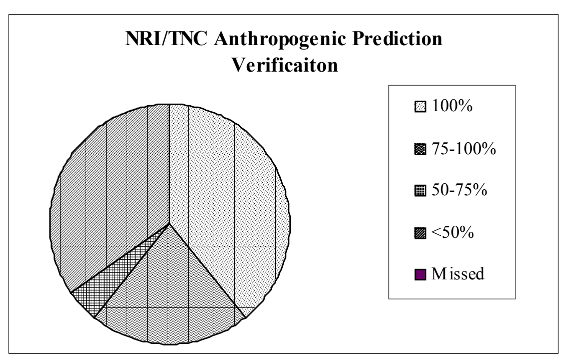
A final map of alien species distribution was created by adding the values of the combined environmental and anthropogenic results of each species group. This gave a final 'probability landscape' onto which key burn and riparian variables could be overlain (Figure 32).

ii. Results of GARP for NRI/TNC Plots

The TWINSPAN and CCA of the NRI/TNC plots resulted in three groups versus four, more plots in each species group, and also slightly different species compositions within groups. The community scale analysis also identified five versus three significant environmental data layers: elevation, slope, vegetation alliance (used as a surrogate for percent tree/shrub cover) and, in addition, percent boulder and cobble. The inclusion of these extra data layers together with more input plots for each species group had two effects. First, a much larger proportion of the park is attributed with some degree of probability of invasives occurring. More plots in each species group means increased variation for each environmental and anthropogenic layer. Second, a greater variation in parameters means that it was easier for the model to fit the data, which is reflected in the higher proportion of verification plots attributed with 100% probability (60% and 30% for the environmental and anthropogenic predictions respectively) and fewer verification plots that were failed to be predicted (4% and 0% respectively) (Figure 33 and Table 18).

Figure 33. Accuracy assessment of predictive model for NRI/TNC plots.





NRI/TNC Species Group 1

Species group one is dominated by similar species as the TNC98/99 group one – namely *Bromus Tectorum, B. Hordeaceus*, and *Vulpia myuros hirsuta* and we see similar, albeit more exaggerated pattern reflected in the probability landscape (Figure 34). Lower elevations are favored with a concentration of high probability areas along the western boundary of the park and, as in TNC98/99 maps, extending eastwards along the Merced and Tuolumne Rivers. The prediction derived from the anthropogenic data layers also shows a much wider distribution - which again is a result of the increased variation associated with a greater number of input plots (Figure 35). Interestingly, it is possible to see the mediating effect of the campgroups in the Yosemite Valley. A combination of the environmental results (any probability) and the anthropogenic results (75-100%) shows a concentration in the western portion of the park. Two other major sections along Tioga Road are also depicted - by Lake Tenaya and also near the Tioga Pass Entrance - but this is doubtful as the elevation is beyond the species' tolerance (Figure 36).

NRI/TNC Species Group 2

This group is dominated by *Rudbeckia californica* and *Holcus lanatus*, characteristically species limited to meadows, riparian zones, and areas less than 2000 m (http://www.fs.fed.us/database/feis/plants) (Figure 37). However, the presence of other species in this group, such as *Senecio altissimum*, or other high elevation training plots, is likely to have effected the distribution. The predicted area for this species group covers the majority of the western part of the park cutting across all elevations. The prediction using the anthropogenic variables concentrates around the roads on the southwestern boundary and also along Tioga Road eastwards across the park (Figure 38). Highest probability areas once these two layers were combined focuses along the Big Oak Flat Road, Wawona area, and along the Yosemite Valley (Figure 39).

NRI/TNC Species Group 3

As with TNC98/99 species group four, this group is dominated by *Poa pratensis* and *Cirsium vulgare*, and has the broadest probability landscape (Figure 40). A reflection of both the increased variation in training plots and the inclusion of two extra data layers which are both extremely coarse. For example, eight of the training data records are above 4000 m in elevation, versus a maximum of 2900 m for the comparative species group in the TNC98/99 plots, which obviously influences the results of the model. Interestingly, for this species group it was possible to see the influence of distance to trails on alien species cover seen in the prediction based on the anthropogenic factors (Figure 41). Even after selecting areas with >75% probability from the anthropogenic grid, the combined map still covers a vast proportion of the park (Figure 42).

As with the combined predictions for the TNC98/99 plots, the results from all three NRI/TNC species groups were combined to give a final 'probability landscape' (Figure 43).

iii. Evaluation of Results from TNC98/99 and NRI/TNC Predictions

Comparing the results of the TNC98/99 and NRI/TNC probability landscapes we recommend that the results from the TNC98/99 plots be used. We feel that the probabilities generated from the NRI/TNC plots are an overestimation of the actual areas that are prone to alien invasions (Figure 43). This broader probability landscape is a reflection of both the increased variation of input variables and the use of two coarse soil related grids. In contrast, the predictions using the TNC98/99 plots are more reasonable, reflecting to some extent descriptions of particular alien species in the literature, despite the verification plot assessment not being as good as we would like. Consequently, we are satisfied that the TNC98/99 predictions provide a solid foundation for refining the areas to be sampled and the following analysis and maps focus only on this data set.

iv. Discussion of Predictive Model Results

The accuracy assessment of the predictive models for the TNC98/99 and NRI/TNC plots using the verification points raise some interesting data related questions and considerations:

- Would the predictive accuracy be increased if the cover of each alien species had been higher?

A higher amount of alien species cover would mean more confidence in suggesting that this is determined by either the environmental, anthropogenic, or a combination of these factors at the site. However, over half of the TNC98/99 plots used for prediction had an alien species cover of 1%. This could potentially cause confusion, as the model is using the plot as a 'positive' alien location record, but in reality this low cover could be indicating that the site characteristics are not optimal, and the invasive will not increase in those conditions.

- Would the predicted patterns be different if other environmental or anthropogenic variables are used?

In the CCA and the predictive model we are generating a probability surface based on a limited number of data layers. The spatial patterns might be significantly different if additional data was utilized; such as precipitation, evapotranspiration rates, or on the anthropogenic disturbance side, the amount of foot traffic on trails.

- Would the predicted patterns be different at a finer scale of resolution?

In the current analysis all environmental variables related to the alien species cover is linked to the entire plot, which in turn is linked to the information in a 30 m resolution gridcell. However, factors such as slope and percent tree and shrub cover can vary considerably over a 30 m area. The correlation between alien cover and the physical location would be greatly improved if the actual physical location of the invasion had been recorded (GPS polygon) and if this could be linked to data at the 10 m rather than 30 m gridcell resolution.

- Would different predicted patterns emerge with more widespread sampling?

The predicted probability patterns are obviously a result of the location input plots – which, for the TNC98/99 plots, are concentrated along the Yosemite Valley and along Tioga Road. These locations are reflected particularly when using the anthropogenic data layers – areas adjacent to roads having highest probability of an alien cover. A wider distribution across the landscape of input plots with alien cover would have generated a very different pattern of predicted alien cover.

C. INTEGRATING PROBABILITY SURFACE WITH KEY FIRE AND RIPARIAN VARIABLES

C.1. Selecting Key Burn Variables

The community scale analyses found no relationship between alien species and burn variables; however, a relationship did exist between all species and burn variables. Consequently, we used year of burn and burn size as simplified measures for refining sampling locations within the probability landscapes for the alien species groups. We first selected all burns since 1990, the premise being the more recent the burn the greater the chance of encountering alien species and reselected for the largest quarter of these burns (using natural breaks) (Table 19). In addition to the Ackerson fire, which dominated in size (23,938 ha), four fires were selected ranging from 2318-7191 ha. The next three largest fires after these all occurred in the 1970's, which we considered too long ago for sampling to encounter new disturbance-generated alien species. Where necessary the burn polygons were clipped to the boundary of the park and overlain onto the TNC98/99 based probability landscape (Figure 44).

Table 19. Key burn areas and number of random points generated.

Name	Year	Type	Cause	Hectares	Perimeter	No. random points
Ackerson	1996	WF	LTG	23938	93655	118
A-rock	1990	WF	LTG	7191	61328	35
Hoover	2001	WFRB	LTG	3693	37987	18
Leconte	1999	WFRB	LTG	3586	40989	18
Steamboat	1990	WF	LTG	2318	25508	11

C.2. Selecting Key Riparian Variables

Selecting key riparian variables was more difficult since none of them (riparian vegetation, existence within a 50 m river buffer, stream order, or distance to stream) were significant. Consequently we used our best judgment and took a multi-step approach in an attempt to capture true riparian areas.

We first selected polygons from the 1937 vegetation map (vtm_1982.shp) labeled as any type of 'meadow'. From these derived polygons the six largest ones were separated into one shapefile and the remaining ones (< 105 ha) reselected for those occurring below 2772 m - which approximates the upper limit of the probability landscape - leaving 31 polygons (Table 20). However, one concern of using these riparian polygons is the accuracy of the classification, and also a concern that only a fraction of the Merced and Tuolumne Rivers were captured within these areas. To ensure that sampling did encompass these we generated a 30 m buffer each side of the river sections that fell within the probability landscape and added these to the areas we consider to be 'riparian'. Figure 45 shows the overlay of all these approaches to categorizing riparian areas with the probability landscape.

Table 20. Key riparian areas and number of random points generated.

Large riparian polygons	Area (m)	Perimeter (m)	No. random points
1	18750694	38311	69
2	4214803	15656	16
3	3922629	22402	14
4	2941886	11038	11
5	2205837	11774	8
6	1052155	8952	4
Small riparian poly (n=31)	10423997	108466	38
Merced River buffer	4557468	77175	20
Tuolumne River buffer	6113712	116069	20

D. GENERATION OF RANDOM POINTS FOR FIELD SAMPLING STARTING LOCATIONS

Once the key burn and riparian polygons had been selected the final step was to generate random points for sampling at the intersection of these areas with the probability landscape created by the combination of anthropogenic and environmental results of each of the TNC98/99 species groups. The recommended number of sampling sites based on the community scale analysis was 150 in each of the key burn and riparian areas. An extra 50 points for each was generated to provide some leeway for plots that could be substituted if terrain or other confounding factors made access to them impossible.

D.1. Random Sampling Points in Burn Areas

The number of random points generated in each fire is proportional to its area, the largest fire (Ackerson) receiving 118 points and the smallest burn (Steamboat) just 11 (Table 19). In generating the random points a distance of 10 m was specified from the edge of the burn – to omit any spurious edge effects from sampling, with a minimum of 300 m in between points to allow 1 ha plots to be conducted independently (Figure 44). Table 21 gives the coordinates of the 200 generated points for fieldwork sampling. However, we recommend that these points are filtered to select locations greater than 50 m from the edge, since the edge might be difficult to detect in the field. We also recommend that field crews are supplied with more than the required 150 sampling points, so that points that are located in unburned areas, owing to the patchiness of the fire, are omitted.

D.2. Random Sampling Points in Riparian Areas

The generation of random points for the intersection of riparian areas with the probability landscape was again proportional to the area of the riparian polygons, with 20 points allocated to each of the Merced and Tuolumne River buffers (Table 20). For the large polygons and two riparian buffers these were generated automatically in Arcview. The premise for this is that the larger the polygon, the more confident we were that it was indeed correctly classified as 'riparian' and no further manipulation was necessary. However, for the smaller polygons, points were generated manually within a 30 m distance from streams, to ensure the maximum likelihood of encountering a true riparian area. Of the 34 points allocated to these smaller riparian polygons most received two points, some one, and none if the polygon had no stream within it. The random points generated in the river buffers were cross-referenced to ensure that any points adjacent to the riparian polygons were included within it and moved if necessary. The final 200 generated points were combined and their UTM coordinates calculated (Figure 45 and Table 22).

D.3. Discussion of Random Sampling

Based on the predicted alien species distribution combined with the key fire and riparian variables, we believe that this provides the best chance of sampling alien species. These points can obviously be refined in a number of ways, for example, limited to areas of very high probability or to areas that are predicted based on environmental data layers alone. However, we felt that including results from the environmental and anthropogenic models - driven primarily by the environmental niche of the alien species groups, provided the best chance of encountering alien species. Also, sampling across the spectrum of probabilities will provide important information for both monitoring alien species at a variety of stages of invasion in future years and also verifying how well the predictive model worked. To sample the highest probability areas the list of fieldwork coordinates can be sorted in descending order.

When finalizing the choice of sampling locations and planning fieldwork, these GIS files can be overlain with road and trail networks to give an indication of the accessibility of sites and their feasibility for fieldwork and also sampling points can be manually relocated to areas of the highest predicted likelihood of encountering invasives.

E. TABLES

Table 17. TNC98/99 Species Group Prediction Results

Species Group 1

PLOT	ACRONYM	COVER	SP_GRP	STATUS	ENV_PROB	ANTH_PROB
99K37	BRHO2	3	1	Input plot	0.55	0.60
98K36	BRHO2	3	1	Input plot	0.80	0.60
98K26	BRTE	3	1	Input plot	0.70	0.90
98K31	BRTE	1	1	Input plot	1.00	0.95
98K27	AICA	1	1	Input plot	1.00	0.85
98K32	BRTE	15	1	Input plot	1.00	0.95
98M27	BRTE	3	1	Input plot	0.60	0.85
98M29	VUMY	38	1	Input plot	0.90	0.50
98K63	VUMY	15	1	Input plot	0.95	0.90
99K53	BRHO2	15	1	Input plot	0.80	0.30
99S47	BRAR3	3	1	Input plot	0.50	1.00
99K31	BRTE	1	1	Verification plot	0.60	0.00
99K41	AICA	1	1	Verification plot	0.75	0.20
99K46	BRTE	1	1	Verification plot	0.25	0.05

Species Group 2

PLOT	ACRONYM	COVER	SP_GRP	STATUS	ENV_PROB	ANTH_PROB
98K29	TRDU	1	2	Input plot	0.45	0.80
98K24	LASE	1	2	Input plot	1.00	0.85
98M34	LASE	1	2	Input plot	1.00	0.85
98M35	HOLA	1	2	Input plot	0.80	0.75
98M33	HOLA	1	2	Input plot	0.85	0.85
98K36	DIAR	1	2	Input plot	0.90	0.95
98K26	HOLA	3	2	Input plot	0.80	1.00
98M24	LASE	1	2	Input plot	0.65	0.85
98K31	HOLA	1	2	Input plot	1.00	0.95
98K27	HOLA	3	2	Input plot	1.00	0.65
98K32	DIAR	1	2	Input plot	0.80	0.90
98M27	HOLA	3	2	Input plot	1.00	0.95
98M28	LASE	1	2	Input plot	1.00	0.95
98M29	LASE	1	2	Input plot	1.00	0.80
99K114	HOLA	1	2	Verification plot	1.00	0.90
99S49	HOLA	1	2	Verification plot	0.70	0.80
99K36	LEVU	1	2	Verification plot	0.00	0.90
99S47	TRDU	1	2	Verification plot	0.00	0.95

Species Group 3

PLOT	ACRONYM	COVER	SP_GRP	STATUS	ENV_PROB	ANTH_PROB
98K30	HYSCS2	1	3	Input plot	0.70	0.85
98K28	HYSCS2	3	3	Input plot	0.65	0.95
98M31	RUAC3	38	3	Input plot	0.95	1.00
98M34	RUAC3	1	3	Input plot	0.95	1.00
99K49	RUAC3	1	3	Input plot	0.50	1.00
99K114	AGGI2	38	3	Input plot	1.00	1.00

Table 17 continued.

Species Group 3

PLOT	ACRONYM	COVER	SP_GRP	STATUS	ENV_PROB	ANTH_PROB
98K33	RUAC3	3	3	Input plot	1.00	0.95
98M32	RUAC3	15	3	Input plot	1.00	1.00
98M35	RUAC3	1	3	Input plot	1.00	0.95
98M33	RUAC3	15	3	Input plot	1.00	1.00
98K36	AGGI2	3	3	Input plot	0.65	1.00
98K26	RUAC3	15	3	Input plot	0.65	1.00
98K35	HYSCS2	1	3	Input plot	1.00	0.95
98K31	RUAC3	3	3	Input plot	1.00	0.85
98K27	RUAC3	1	3	Input plot	1.00	0.55
98M27	RUCR	3	3	Input plot	1.00	0.65
98M29	RUAC3	15	3	Input plot	1.00	0.45
99K163	PHPR3	1	3	Input plot	1.00	1.00
99K128	RUAC3	1	3	Input plot	0.95	1.00
99K99	PHPR3	1	3	Input plot	1.00	1.00
98M64	PHPR3	1	3	Input plot	0.95	1.00
98M72	PHPR3	1	3	Input plot	0.75	1.00
98M60	RUAC3	1	3	Input plot	0.65	1.00
98M62	RUAC3	3	3	Input plot	0.75	1.00
99S52	RUAC3	1	3	Verification plot	0.20	0.10
99S49	RUAC3	1	3	Verification plot	0.85	1.00
99S137	PHPR3	1	3	Verification plot	1.00	1.00
99S138	PHPR3	1	3	Verification plot	0.00	0.00

Species Group 4

PLOT	ACRONYM	COVER	SP_GRP	STATUS	ENV_PROB	ANTH_PROB
98M30	CIVU	1	4	Input plot	0.75	1.00
98K30	POPR	38	4	Input plot	0.90	1.00
98K28	POPR	15	4	Input plot	0.75	1.00
98K29	POPR	38	4	Input plot	0.75	1.00
98M16	CIVU	1	4	Input plot	1.00	1.00
98M34	POPR	3	4	Input plot	1.00	1.00
99K49	POPR	3	4	Input plot	0.85	1.00
98M15	POPR	3	4	Input plot	1.00	0.85
98K33	POPR	15	4	Input plot	1.00	0.95
98M32	POPR	15	4	Input plot	1.00	0.85
98M35	CIVU	1	4	Input plot	1.00	0.80
98M33	POPR	15	4	Input plot	1.00	0.85
98K36	POPR	3	4	Input plot	0.95	1.00
98K26	POPR	88	4	Input plot	0.35	1.00
98K35	MYDI	1	4	Input plot	1.00	1.00
98K27	CIVU	1	4	Input plot	1.00	0.55
99K40	CIVU	3	4	Input plot	1.00	0.85
98M28	POPR	3	4	Input plot	1.00	0.45
98K25	POPR	1	4	Input plot	0.80	1.00
98M63	POPR	1	4	Input plot	1.00	0.80
98M64	POPR	15	4	Input plot	0.95	0.90

Table 17 continued.

Species Group 4

PLOT	ACRONYM	COVER	SP_GRP	STATUS	ENV_PROB	ANTH_PROB
98M65	CIVU	1	4	Input plot	1.00	0.85
98M72	POPR	15	4	Input plot	0.95	0.95
98M71	POPR	3	4	Input plot	0.95	1.00
99K102	POPR	1	4	Input plot	0.70	0.95
98K87	POPR	1	4	Input plot	0.40	0.95
99S49	TAOF	1	4	Verification plot	0.85	1.00
99S121	POPR	1	4	Verification plot	0.75	0.00
99S119	POPR	1	4	Verification plot	0.75	0.00
99S106	POPR	1	4	Verification plot	0.60	0.85
99K107	POPR	1	4	Verification plot	0.50	0.00
99S138	POPR	1	4	Verification plot	0.00	0.00

Table 18. NRI/TNC Species Group Prediction Results

Species Group 1

PLOT	ACRONYM	COVER	SP_GRP	STATUS	ENV_PROB	ANTH_PROB
T98M29	VUMY	37.50	1	Input plot	0.95	0.50
T98K32	BRTE12	15.00	1	Input plot	1.00	0.85
T98K63	VUMY	15.00	1	Input plot	1.00	1.00
T99K53	BRHO11	15.00	1	Input plot	1.00	1.00
NRI227	BRTE12	5.50	1	Input plot	0.95	0.30
NRI318	VUMY	4.17	1	Input plot	1.00	1.00
NRI005	VUMY	3.33	1	Input plot	1.00	1.00
NRI001	BRTE12	2.50	1	Input plot	0.65	0.20
NRI045	BRTE12	2.50	1	Input plot	0.35	0.25
T98K26	BRTE12	2.50	1	Input plot	0.95	1.00
T98K36	BRHO11	2.50	1	Input plot	1.00	1.00
T98K36	BRTE12	2.50	1	Input plot	1.00	1.00
T98M27	BRTE12	2.50	1	Input plot	0.95	0.70
T99K37	BRHO11	2.50	1	Input plot	0.60	0.35
T99S47	BRAR3	2.50	1	Input plot	1.00	0.90
NRI268	BRTE12	1.67	1	Input plot	1.00	0.50
NRI043	BRTE12	1.25	1	Input plot	0.65	0.25
NRI267	BRTE12	1.17	1	Input plot	1.00	0.75
NRI026	VUMY	1.00	1	Input plot	1.00	0.35
NRI042	BRTE12	1.00	1	Input plot	0.70	0.35
NRI048	BRDI10	1.00	1	Input plot	0.95	1.00
NRI055	AICA	1.00	1	Input plot	1.00	0.40
NRI082	BRHO11	1.00	1	Input plot	1.00	0.95
NRI298	BRTE12	1.00	1	Input plot	1.00	0.70
NRI299	VUMY	1.00	1	Input plot	1.00	0.80
NRI319	BRTE12	1.00	1	Input plot	1.00	0.20
NRI321	VUMY	1.00	1	Input plot	1.00	0.20
NRI359	BRTE12	1.00	1	Input plot	0.65	0.05
NRI066	LEVU10	0.83	1	Input plot	0.00	0.50
NRI228	BRTE12	0.83	1	Input plot	0.90	0.10
NRI315	VUMY	0.50	1	Input plot	1.00	0.90
T98K24	LASE	0.50	1	Input plot	0.95	0.95
T98K27	AICA	0.50	1	Input plot	1.00	0.65
T98K29	TRDU	0.50	1	Input plot	0.85	0.95
T98K31	BRTE12	0.50	1	Input plot	1.00	0.85
T98M24	LASE	0.50	1	Input plot	1.00	1.00
T98M28	LASE	0.50	1	Input plot	0.95	0.65
T98M34	LASE	0.50	1	Input plot	1.00	0.95
T99K141	POAN	0.50	1	Verification plot	0.00	0.30
T99K31	BRTE12	0.50	1	Verification plot	1.00	0.05
T99K36	LEVU10	0.50	1	Verification plot	1.00	1.00
T99K41	AICA	0.50	1	Verification plot	1.00	1.00
T99K46	BRTE12	0.50	1	Verification plot	1.00	0.95
NRI039	VUMY	0.42	1	Verification plot	1.00	0.40
NRI054	VUMY	0.42	1	Verification plot	1.00	1.00
NRI264	BRTE12	0.33	1	Verification plot	1.00	0.70

Table 18 continued.

Species Group 1

PLOT	ACRONYM	COVER	SP_GRP	STATUS	ENV_PROB	ANTH_PROB
NRI320	BRTE12	0.33	1	Verification plot	1.00	0.85

Species Group 2

PLOT	ACRONYM	COVER	SP_GRP	STATUS	ENV_PROB	ANTH_PROB
NRI066	HOLA10	1.67	2	Input plot	0.00	0.35
NRI174	SIAL10	1.33	2	Input plot	1.00	0.80
T98K26	RUAC3	15.00	2	Input plot	1.00	1.00
T98K27	HOLA10	2.50	2	Input plot	1.00	0.45
T98K31	RUAC3	2.50	2	Input plot	1.00	0.95
T98K32	DIAR	0.50	2	Input plot	0.95	0.85
T98K33	RUAC3	2.50	2	Input plot	1.00	0.95
T98K36	AGGI2	2.50	2	Input plot	1.00	1.00
T98M15	CILAL	0.50	2	Input plot	0.90	0.90
T98M27	HOLA10	2.50	2	Input plot	1.00	1.00
T98M28	TAOF	0.50	2	Input plot	1.00	0.90
T98M29	RUAC3	15.00	2	Input plot	1.00	0.60
T98M31	RUAC3	37.50	2	Input plot	1.00	1.00
T98M32	RUAC3	15.00	2	Input plot	1.00	0.95
T98M33	RUAC3	15.00	2	Input plot	1.00	0.95
T98M34	RUDI2	2.50	2	Input plot	1.00	0.90
T98M35	HOLA10	0.50	2	Input plot	1.00	0.80
T98M60	RUAC3	0.50	2	Input plot	0.85	1.00
T98M62	RUAC3	2.50	2	Input plot	0.75	0.90
T99K113	AGCA5	0.50	2	Input plot	1.00	1.00
T99K114	AGGI2	37.50	2	Verification plot	1.00	1.00
T99K128	RUAC3	0.50	2	Verification plot	0.90	1.00
T99K49	RUAC3	0.50	2	Verification plot	0.95	1.00
T99S49	PONE	15.00	2	Verification plot	1.00	0.95
T99S52	RUAC3	0.50	2	Verification plot	0.85	0.20

Species Group 3

PLOT	ACRONYM	COVER	SP_GRP	STATUS	ENV_PROB	ANTH_PROB
T98K26	POPR11	87.50	3	Input plot	0.75	1.00
T98K29	POPR11	37.50	3	Input plot	1.00	1.00
T98K30	POPR11	37.50	3	Input plot	1.00	1.00
T98K28	POPR11	15.00	3	Input plot	1.00	1.00
T98K33	POPR11	15.00	3	Input plot	1.00	1.00
T98M32	POPR11	15.00	3	Input plot	1.00	1.00
T98M33	POPR11	15.00	3	Input plot	1.00	1.00
T98M64	POPR11	15.00	3	Input plot	1.00	0.95
T98M72	POPR11	15.00	3	Input plot	1.00	1.00
NRI283	POPR11	6.00	3	Input plot	1.00	1.00
NRI284	POPR11	4.17	3	Input plot	0.85	0.30
NRI130	POPR11	3.75	3	Input plot	0.90	0.05
NRI066	POPR11	3.33	3	Input plot	0.00	0.35

Table 18 continued.

Species Group 3

PLOT	ACRONYM	COVER	SP_GRP	STATUS	ENV_PROB	ANTH_PROB
T98K36	POPR11	2.50	3	Input plot	1.00	1.00
T98M15	POPR11	2.50	3	Input plot	0.75	0.95
T98M27	RUCR	2.50	3	Input plot	1.00	0.80
T98M28	POPR11	2.50	3	Input plot	1.00	0.60
T98M34	POPR11	2.50	3	Input plot	1.00	1.00
T98M71	POPR11	2.50	3	Input plot	1.00	1.00
T99K40	CIVU10	2.50	3	Input plot	1.00	0.95
T99K49	POPR11	2.50	3	Input plot	1.00	1.00
NRI114	POPR11	1.25	3	Input plot	0.25	0.05
NRI131	POPR11	1.00	3	Input plot	0.20	0.05
NRI339	CIVU10	1.00	3	Input plot	0.70	0.15
NRI340	CIVU10	1.00	3	Input plot	0.55	0.00
NRI350	CIVU10	1.00	3	Input plot	0.15	0.20
T98K25	POPR11	0.50	3	Input plot	1.00	1.00
T98K27	CIVU10	0.50	3	Input plot	1.00	0.65
T98K35	HYSCS2	0.50	3	Input plot	1.00	1.00
T98K87	POPR11	0.50	3	Input plot	0.90	1.00
T98M16	CIVU10	0.50	3	Input plot	1.00	1.00
T98M30	CIVU10	0.50	3	Input plot	1.00	1.00
T98M35	CIVU10	0.50	3	Input plot	1.00	1.00
T98M63	POPR11	0.50	3	Input plot	1.00	0.95
T98M65	CIVU10	0.50	3	Input plot	1.00	1.00
T99K102	POPR11	0.50	3	Input plot	0.85	1.00
T99K107	POPR11	0.50	3	Verification plot	0.85	0.35
T99K114	RUCR	0.50	3	Verification plot	1.00	1.00
T99K163	PHPR3	0.50	3	Verification plot	1.00	1.00
T99K99	PHPR3	0.50	3	Verification plot	1.00	0.95
T99S106	POPR11	0.50	3	Verification plot	0.85	0.95
T99S119	POPR11	0.50	3	Verification plot	0.75	0.45
T99S121	POPR11	0.50	3	Verification plot	0.80	0.40
T99S137	PHPR3	0.50	3	Verification plot	1.00	1.00
T99S138	PHPR3	0.50	3	Verification plot	0.70	0.35

Table 21. Burn Sample Points

ID	UTM_X	UTM_Y	Predicted value
1	261224.664	4176712.763	3.30
2	281240.824	4172880.458	0.80
3	280659.928	4173569.427	0.80
4	280225.013	4171721.968	0.55
5	257685.257	4196328.433	1.45
6	258828.200	4180692.893	1.50
7	263770.104	4173787.474	1.00
8	257101.313	4192297.477	1.00
9	258969.685	4173241.761	0.20
10	252912.146	4197208.377	1.80
11	259439.284	4178837.022	1.25
12	265087.995	4172136.544	3.55
13	272252.206	4202753.349	1.25
14	279096.896	4167978.287	0.55
15	252274.038	4192438.246	2.60
16	256841.090	4174636.294	1.10
17	273460.113	4203220.923	2.00
18	278898.470	4169298.996	0.45
19	251032.804	4204308.093	2.05
20	260052.356	4172522.000	2.25
21	251542.274	4201556.200	0.85
22	255254.491	4177881.794	4.30
23	262543.044	4176860.819	1.10
24	272520.230	4201704.706	2.10
25	281512.226	4168628.299	0.25
26	249837.269	4205045.059	0.50
27	259397.185	4172501.400	0.95
28	263366.658	4201602.965	0.65
29	281839.973	4170151.471	0.45
30	259974.972	4174083.898	1.15
31	280196.793	4169012.853	0.60
32	250716.289	4202834.712	1.30
33	256929.900	4178278.795	2.35
34	260928.120	4174177.993	0.60
35	282551.684	4170939.070	0.55
36	253594.261	4205656.713	1.25
37	255737.391	4177112.558	1.30
38	260202.170	4175008.607	1.15
39	247387.523	4206404.720	1.00
40	260128.771	4178039.230	5.70

Table 21 continued.

ID	UTM_X	UTM_Y	Predicted value
41	258787.784	4172291.215	1.30
42	279648.845	4171773.680	0.80
43	247410.091	4202518.949	1.05
44	257133.710	4176657.435	4.95
45	267221.656	4199988.197	0.65
46	281893.746	4171519.818	0.55
47	263414.684	4196499.564	0.45
48	261815.632	4203915.989	0.65
49	281376.683	4166810.522	0.25
50	258216.768	4174494.779	2.60
51	281944.630	4170828.750	0.35
52	282078.395	4172177.979	0.45
53	251584.589	4192384.147	1.00
54	257399.618	4175855.094	4.50
55	267593.135	4199770.107	1.15
56	248465.705	4206855.732	2.30
57	268012.947	4199862.950	0.95
58	280957.389	4169316.861	0.45
59	256485.209	4203679.325	0.15
60	258290.834	4175397.444	3.00
61	255919.319	4198742.480	1.80
62	257728.664	4177704.900	2.95
63	247619.408	4203303.942	0.70
64	257690.503	4178192.117	3.75
65	251040.138	4199062.661	0.65
66	259472.588	4176286.210	1.05
67	280632.975	4172651.541	0.55
68	249427.097	4198806.516	0.15
69	265489.284	4202514.609	1.30
70	277855.235	4169278.625	0.50
71	255132.828	4198087.768	1.35
72	256687.409	4175268.564	1.20
73	280316.560	4168415.494	0.60
74	262660.352	4199455.709	0.60
75	257759.192	4176785.304	3.85
76	251534.375	4206337.924	1.35
77	258608.258	4175047.446	2.75
78	247522.366	4205067.140	0.65
79	251577.254	4201123.405	1.10
80	256621.669	4178154.716	3.20
81	263792.132	4196538.207	0.60

Table 21 continued.

ID	UTM_X	UTM_Y	Predicted value
82	259502.943	4175962.999	1.35
83	256186.749	4196147.918	1.70
84	266328.108	4202760.232	0.65
85	255567.925	4178202.225	4.45
86	259060.207	4193516.370	1.10
87	256265.564	4177349.848	3.45
88	271759.297	4201677.508	0.95
89	259831.294	4175855.346	1.80
90	268727.945	4200080.033	0.65
91	249270.815	4198271.043	0.70
92	251789.393	4191850.329	2.95
93	258190.056	4178315.437	4.30
94	267965.014	4201655.011	0.65
95	258692.914	4201707.458	0.65
96	251246.070	4198629.313	1.90
97	258918.050	4178190.095	1.55
98	261171.999	4196151.230	1.25
99	258318.413	4176309.206	4.50
100	247930.845	4206136.983	0.65
101	256526.442	4174817.989	2.55
102	258112.919	4194341.109	1.25
103	257390.598	4178702.835	3.45
104	254714.193	4201409.911	0.65
105	255927.152	4178768.539	1.25
106	270414.781	4200619.464	3.00
107	258797.498	4178541.356	1.30
108	264381.237	4201445.316	0.95
109	248280.648	4198837.430	2.05
110	259876.913	4176985.447	1.55
111	261616.586	4195695.250	0.80
112	255711.373	4177447.140	1.85
113	256313.129	4202924.694	0.65
114	258717.882	4177192.665	3.75
115	251485.854	4195528.535	0.35
116	260206.826	4179994.162	1.95
117	255311.904	4178613.883	1.60
118	252412.831	4198916.923	3.00
119	258091.013	4177218.189	2.80
120	249609.897	4201039.496	0.65
121	266500.666	4200684.941	1.00
122	252161.763	4195307.722	2.00

Table 21 continued.

ID	UTM_X	UTM_Y	Predicted value
123	251360.038	4199258.081	1.05
124	263221.662	4202660.002	1.80
125	260115.257	4197895.660	0.65
126	255837.510	4194203.653	0.95
127	251190.779	4205806.866	1.05
128	263889.526	4203384.952	1.15
129	249488.595	4197817.823	0.65
130	249034.416	4204507.377	1.85
131	256643.185	4196534.342	1.90
132	261495.284	4197817.823	0.30
133	252332.151	4191246.404	3.00
134	251480.212	4194829.660	2.90
135	248602.240	4200197.091	1.75
136	255893.930	4204777.874	1.30
137	261560.731	4194671.226	0.75
138	251669.783	4200590.692	0.25
139	260255.742	4199995.599	1.50
140	256826.549	4200417.905	1.90
141	248927.218	4207252.645	2.35
142	247149.432	4204134.202	0.70
143	257350.124	4203417.661	1.90
144	256911.743	4199409.890	1.35
145	248919.319	4201575.522	1.75
146	252276.859	4198075.623	1.30
147	263464.898	4195776.951	0.70
148	255259.208	4196894.821	1.95
149	249969.291	4205504.351	1.80
150	261068.750	4195036.673	1.25
151	260834.608	4195994.453	1.50
152	247062.545	4202945.671	3.65
153	255693.076	4198140.211	1.30
154	255825.662	4192371.450	1.00
155	259249.213	4202725.410	0.60
156	250066.333	4200485.806	1.50
157	259899.169	4195970.163	1.45
158	250152.655	4204676.300	0.60
159	248391.795	4206419.073	2.95
160	261511.646	4198873.865	0.45
161	255671.636	4197218.313	1.15
162	250629.967	4205402.777	2.30
163	253771.419	4198926.860	2.10

Table 21 continued.

ID	UTM_X	UTM_Y	Predicted value
164	248184.734	4200660.248	1.80
165	249803.417	4198944.525	0.60
166	251979.527	4204841.910	2.85
167	252403.804	4190723.627	2.95
168	248306.601	4200982.085	1.30
169	256983.396	4199883.536	1.20
170	258382.606	4195874.109	1.65
171	258028.854	4198870.000	1.60
172	261166.357	4197116.187	0.70
173	252265.011	4194007.680	1.25
174	256956.878	4198802.652	1.25
175	253016.522	4198795.476	2.75
176	247679.777	4198601.160	1.30
177	247939.308	4202680.143	0.70
178	250598.936	4197900.076	2.00
179	256321.592	4199230.479	1.60
180	249011.284	4197726.737	0.25
181	247388.087	4197817.271	0.25
182	252830.337	4190407.311	2.80
183	256386.475	4197302.222	1.50
184	254124.042	4203245.426	0.20
185	263647.698	4197030.069	0.70
186	259507.052	4195889.566	1.30
187	250184.250	4199015.738	0.55
188	253318.932	4206501.326	1.75
189	247714.193	4199530.786	2.60
190	258068.912	4197220.521	0.85
191	262998.870	4196582.921	0.60
192	247537.600	4205512.080	0.80
193	255392.358	4191291.118	1.05
194	249470.541	4203954.791	2.95
195	262083.742	4199240.968	0.75
196	246894.979	4203800.773	1.35
197	254908.277	4198919.132	1.00
198	262911.420	4198159.532	0.65
199	249686.064	4206270.023	1.80
200	252004.352	4194591.181	1.30

Table 22: Riparian Sample Points

ID	UTM_X	UTM_Y	Predicted value
1	252413.170	4200475.052	0.50
2	249035.026	4198705.749	0.50
3	273729.326	4201246.150	2.80
4	264412.251	4200930.890	0.15
5	262665.175	4201388.372	0.40
6	262490.066	4201940.790	0.05
7	265391.523	4200133.949	0.15
8	269214.733	4199800.378	1.65
9	266135.611	4199745.019	0.15
10	261986.555	4202257.909	0.25
11	268182.738	4199897.045	3.30
12	248360.498	4198020.865	0.30
13	255016.778	4203716.534	0.30
14	254133.359	4201918.174	0.20
15	251572.035	4200028.413	0.30
16	257751.611	4204279.251	1.15
17	261646.377	4202023.239	0.70
18	267800.707	4199662.488	3.60
19	260610.780	4203073.421	0.15
20	263014.986	4201244.908	0.05
21	274549.071	4179619.591	5.50
22	270175.724	4179451.832	6.45
23	267853.812	4177934.095	5.85
24	257666.906	4173316.546	0.25
25	273476.045	4180439.311	3.60
26	262092.430	4178048.991	4.20
27	262444.984	4178019.725	4.35
28	259462.052	4174335.061	0.70
29	258041.293	4173110.777	0.20
30	280782.648	4178842.571	1.35
31	276134.320	4178399.673	1.95
32	271021.992	4179695.952	5.05
33	271726.051	4180350.508	4.35
34	272621.996	4180378.344	4.60
35	278458.969	4178778.659	1.35
36	259779.805	4175355.626	0.30
37	261179.509	4178299.225	4.25
38	266163.783	4177824.619	4.85
39	264926.609	4177523.794	3.65
40	274619.854	4178614.125	2.95

Table 22 continued.

ID	UTM_X	UTM_Y	Predicted value
41	266192.027	4156743.788	7.40
42	266793.641	4156363.128	6.30
43	261650.317	4168169.490	2.00
44	262493.560	4167727.533	2.45
45	264130.084	4167848.525	1.95
46	263609.882	4166718.451	1.05
47	266055.416	4171073.996	0.75
48	265223.433	4174944.218	1.25
49	265483.126	4174666.736	0.85
50	257418.803	4176376.062	6.45
51	257580.369	4176619.997	4.80
52	266048.548	4186079.215	0.50
53	266672.675	4185810.552	0.20
54	253337.839	4182635.488	4.75
55	253226.002	4182060.879	4.80
56	248212.882	4186725.987	5.60
57	247590.143	4186849.360	4.50
58	256295.383	4193330.779	1.35
59	257286.918	4193451.611	1.50
60	254486.062	4196961.392	1.95
61	255033.176	4197678.199	1.95
62	264675.130	4197362.218	3.55
63	264215.054	4193756.386	0.70
64	265204.462	4193190.122	0.50
65	251832.166	4205589.388	2.80
66	251351.321	4205451.681	2.80
67	257509.567	4200449.823	1.75
68	257896.110	4200427.415	1.75
69	261980.842	4209052.158	0.75
70	264182.454	4208775.168	1.50
71	263420.843	4219069.969	0.05
72	263583.331	4206138.103	2.00
73	289036.869	4202781.238	0.15
74	289359.307	4196760.642	0.30
75	282538.629	4188896.071	0.50
76	282791.165	4188995.298	0.15
77	277678.619	4185136.258	0.70
78	281608.225	4161799.506	0.45
79	266309.246	4172791.866	4.50
80	266247.018	4173266.509	1.25
81	267222.720	4174999.104	1.20

Table 22 continued.

ID	UTM_X	UTM_Y	Predicted value
82	265908.745	4172484.241	4.15
83	290655.441	4194303.925	3.20
84	292423.459	4194600.404	2.05
85	289810.136	4194682.114	3.95
86	292106.754	4194785.553	3.10
87	292755.822	4194804.283	3.20
88	291447.078	4194252.153	3.20
89	290253.246	4194477.077	2.75
90	293078.463	4194670.802	3.10
91	280527.957	4171563.438	0.65
92	280228.158	4172754.311	0.65
93	280307.211	4173405.636	0.65
94	279699.825	4171937.136	0.80
95	280794.343	4173646.468	0.80
96	280374.624	4172374.481	0.75
97	281681.514	4172789.061	0.80
98	281211.466	4172684.533	0.80
99	279730.893	4172338.059	0.80
100	280194.242	4171972.536	0.80
101	280850.534	4172802.162	0.80
102	274185.912	4169776.449	0.40
103	275463.101	4169247.019	0.60
104	274018.251	4171610.424	0.90
105	273566.460	4171894.169	0.90
106	272519.714	4173161.582	1.15
107	275009.550	4170163.388	0.65
108	275416.455	4170078.605	0.55
109	273627.188	4172860.045	1.40
110	272915.471	4172563.924	1.25
111	274315.729	4170179.323	0.70
112	274844.823	4170956.140	0.65
113	276275.444	4169783.721	0.60
114	273868.779	4170513.195	0.45
115	272296.078	4172676.465	2.70
116	268580.156	4192831.515	1.35
117	268275.759	4194322.003	0.60
118	267179.039	4193844.088	3.15
119	266965.319	4194558.583	3.25
120	266469.435	4193814.149	0.45
121	267555.693	4194725.980	2.55
122	268209.496	4193108.150	1.20

Table 22 continued.

ID	UTM_X	UTM_Y	Predicted value
123	268086.997	4194915.122	0.55
124	268479.998	4192334.889	3.75
125	269102.850	4192806.229	0.40
126	268728.049	4193287.178	0.50
127	268234.018	4192651.172	3.05
128	269137.943	4193794.122	0.30
129	266845.435	4194253.426	2.05
130	268489.589	4194697.153	0.30
131	268977.843	4192382.933	3.90
132	269486.977	4167589.774	0.75
133	269718.626	4173356.820	1.00
134	268234.864	4173400.309	1.55
135	270644.659	4171131.710	1.15
136	271458.165	4167867.105	0.65
137	270739.090	4169699.081	0.50
138	269977.795	4174031.759	1.20
139	271914.301	4170412.289	0.45
140	269500.171	4172861.551	0.95
141	269892.411	4172333.230	3.35
142	269066.087	4173566.310	1.55
143	268985.415	4172229.106	2.35
144	271385.409	4170819.091	0.55
145	271026.155	4171346.170	0.65
146	269975.344	4171340.951	0.35
147	269953.292	4170312.391	0.55
148	271304.549	4168894.672	0.70
149	269001.625	4171000.251	0.65
150	267816.236	4169988.589	0.65
151	268519.855	4171418.484	1.80
152	270259.205	4170589.722	0.55
153	269393.676	4171984.826	3.75
154	271748.810	4169241.336	0.65
155	270822.967	4168191.652	0.20
156	270357.971	4167955.076	0.65
157	269273.611	4171638.660	1.15
158	268529.467	4171724.891	3.60
159	268183.595	4174955.947	1.15
160	268373.589	4172528.803	2.75
161	271489.265	4172004.707	4.50
162	270787.343	4168594.727	0.25
163	268226.570	4171913.754	0.90

Table 22 continued.

ID	UTM_X	UTM_Y	Predicted value
164	268543.227	4173072.531	0.90
165	269374.828	4169969.951	0.50
166	269009.353	4174455.459	0.80
167	267500.899	4173087.690	1.75
168	269621.933	4169667.770	0.75
169	269120.183	4170645.138	0.65
170	271360.906	4170292.510	0.50
171	269898.254	4170913.026	0.75
172	272716.875	4168168.790	0.75
173	268993.143	4174019.831	1.00
174	270450.518	4172610.561	0.85
175	267492.605	4171752.723	0.50
176	269296.040	4174107.304	1.15
177	267884.091	4172048.692	3.00
178	268969.017	4173197.032	0.95
179	270751.719	4171988.554	3.50
180	270121.610	4171663.261	1.85
181	268435.978	4173854.575	0.55
182	269818.147	4171980.353	3.40
183	270284.462	4171083.252	0.50
184	269154.110	4169132.739	0.65
185	269296.983	4169602.164	0.75
186	271085.151	4169660.314	0.65
187	271039.726	4167817.404	0.75
188	269942.548	4173685.592	1.25
189	271038.972	4170346.684	0.55
190	268972.221	4172619.259	0.90
191	267797.387	4173672.421	1.15
192	270951.326	4170663.030	0.70
193	272187.795	4168200.847	0.70
194	268137.982	4171069.087	0.80
195	267451.327	4170924.209	0.65
196	271098.156	4169265.938	0.65
197	268631.438	4172206.990	4.15
198	268808.992	4175044.663	0.90
199	269983.449	4167629.038	0.75
200	271758.800	4168086.286	0.50

SECTION III: RECOMMENDATIONS

A. From Community Scale Analyses

1. A minimum of 150 1.0 ha plots should be used in the inventory of alien species in burned areas.
2. Plots in burned areas should be 100 m x 100 m in dimension. Presence/absence of all species (native + alien) should be recorded in the plots.
3. Abundance (cover) of alien species (and natives) in burned areas should be estimated in 10 belt transects nested within each 1.0 ha plot. The transects should be 50 m x 2 m in dimension.
4. An equal number of plots (N=150) should be used to inventory alien species in riparian areas. The plots would be 1000 m x 10 m in dimension.
5. Collection of physiographic variables should be done at all plots.
6. We encourage that data on soil moisture and soil depth are collected in the burned plots.

B. From GIS and Predictive Modeling Analyses

We are confident that the GIS analysis and modeling is the best that we could achieve with the data available. However, we do have a number of recommendations that would improve similar work if conducted in the future – which are mainly concerned with the resolution of the data and might be priorities for the Yosemite GIS to acquire.

1. Sort the random sampling points to select > 50 m distance from the edge of burn, select points with the greatest probability, and also select more than the recommended 150 points in case unburned patches are encountered in fieldwork.
2. Using a 10 m DEM: this would bring obvious accuracy advantages for information pertaining to elevation, slope, aspect, and also deriving the stream order classification.
3. Delineating riparian zones: undertaking a more sophisticated modeling of riparian habitat could be conducted with the 10 m DEM. For example, using a least-cost path or visibility function to identify flat areas adjacent to streams and rivers.
4. Improving soil data: the analysis would be greatly improved with finer resolution soil data, particularly since the published literature on alien species often has information related to the preferred site soil characteristics (such as pH or texture). Creation of a park-wide detailed soils layer should be a priority to avoid diluting the analysis by using data at the statewide scale.
5. Recording exact location of alien species: when large areas of alien species are encountered in fieldwork it would be extremely useful if polygons around these patches could be captured using a GPS unit. This would then provide a more detailed digital library of alien species locations for future modeling and GIS activities.

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SECTION V: MAPS (FIGURES)

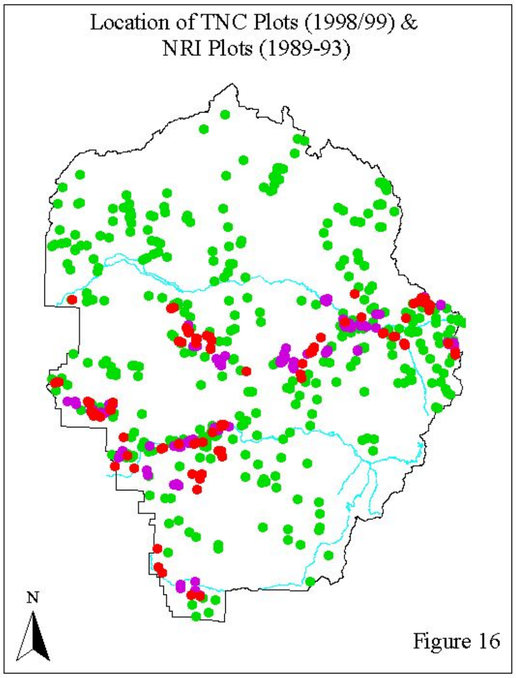


Figure 16

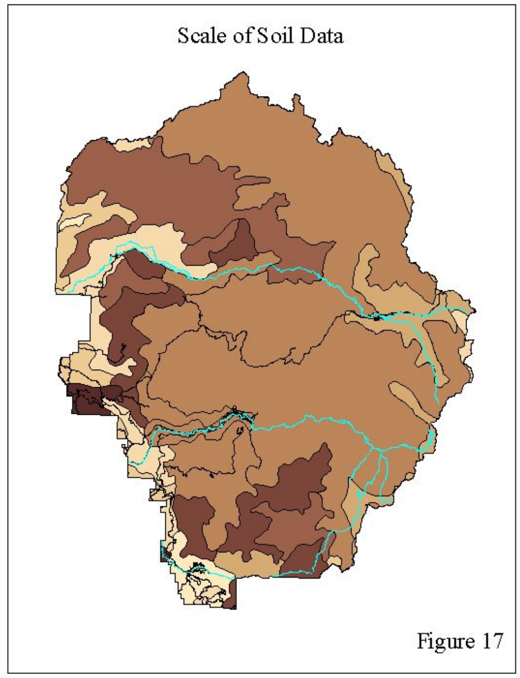


Figure 17

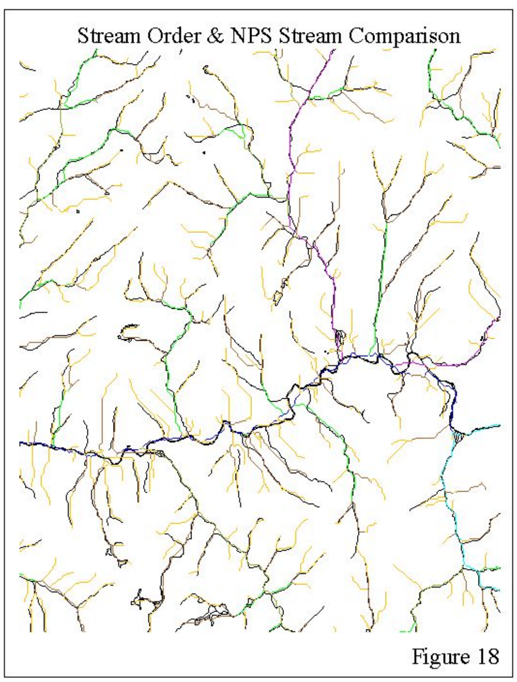


Figure 18

LEGEND

Figure 16
- TNC 1998 plot
- TNC 1999 plot
- NRI plot (1989-93)

Figure 17

Gravel (%)
- 0
- 1
- 2
- 3
- 3-6
- 6-9
- 9-12
- >12

River (from Yosemite GIS)

Figure 18

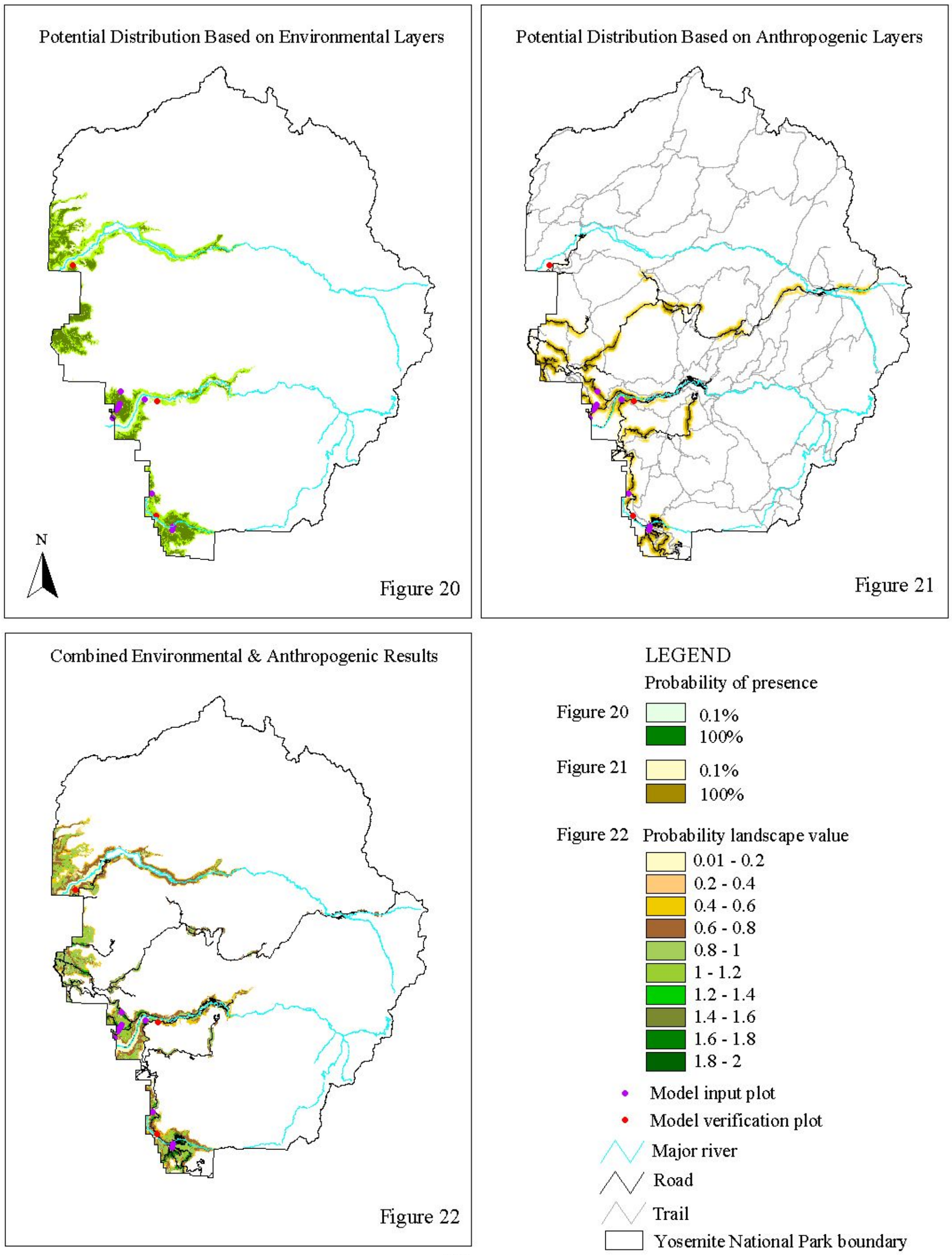
Stream Order
- 1
- 2
- 3
- 4
- 5
- 6
- 7

Streams from Yosemite GIS

Yosemite National Park boundary

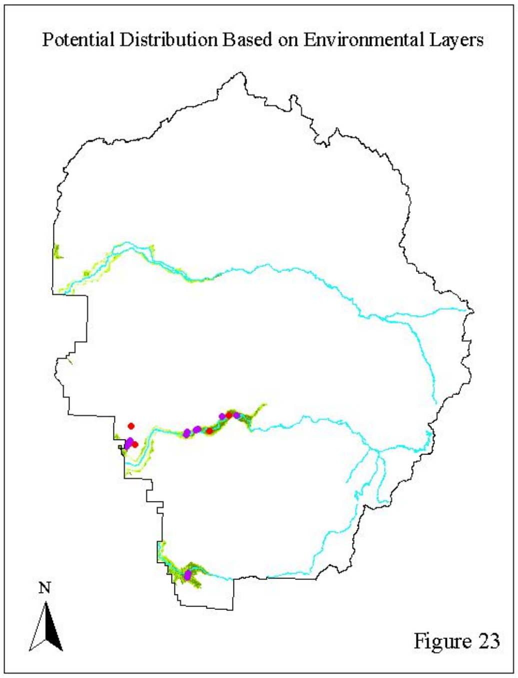
105

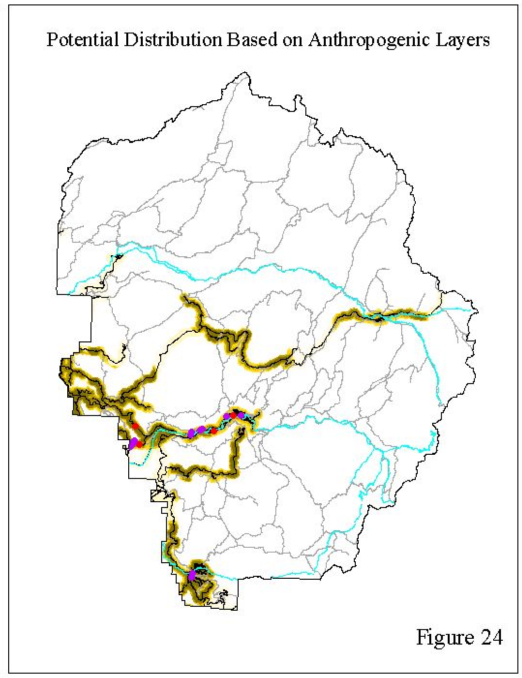
TNC98/99 Plots: Species Group 1

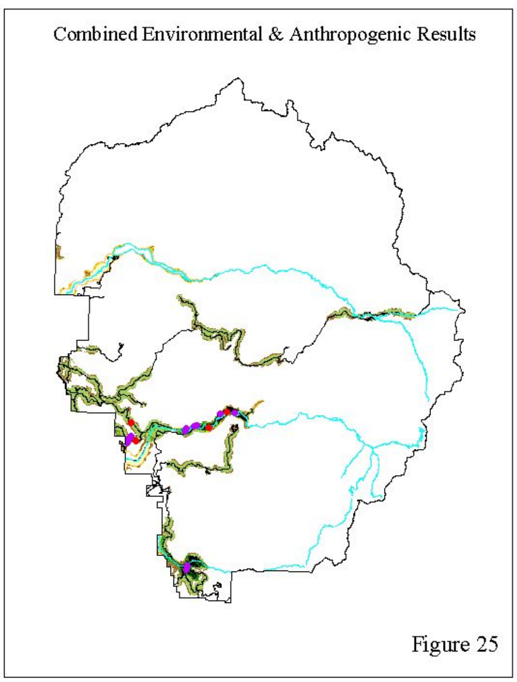


106

TNC98/99 Plots: Species Group 2







LEGEND

Probability of presence

Figure 23: 0.1%, 100%

Figure 24: 0.1%, 100%

Figure 25 Probability landscape value

- 0.01 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1
- 1 - 1.2
- 1.2 - 1.4
- 1.4 - 1.6
- 1.6 - 1.8
- 1.8 - 2

- Model input plot
- Model verification plot
- Major river
- Road
- Trail
- Yosemite National Park boundary

107

TNC98/99 Plots: Species Group 3

Potential Distribution Based on Environmental Layers

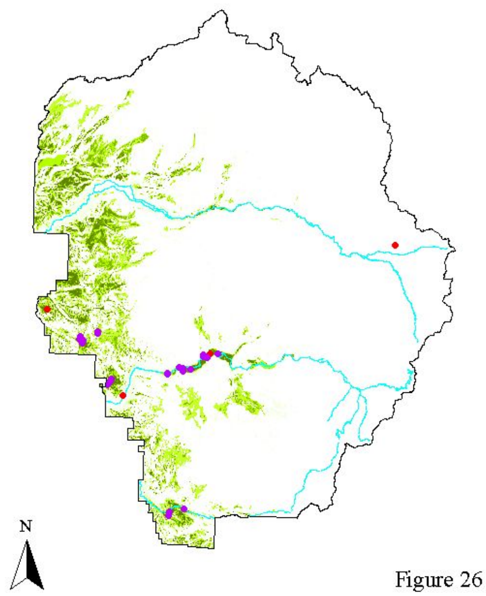


Figure 26

Potential Distribution Based on Anthropogenic Layers

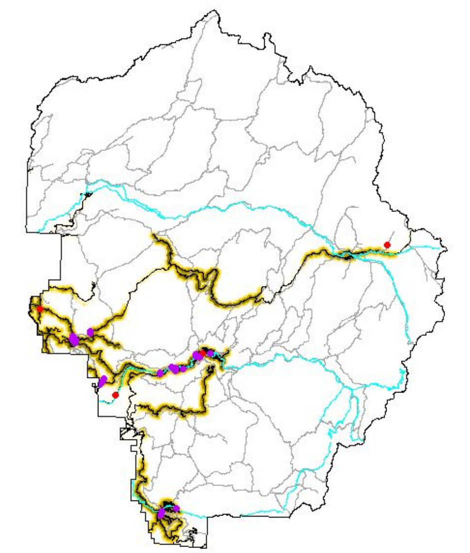


Figure 27

Combined Environmental & Anthropogenic Results

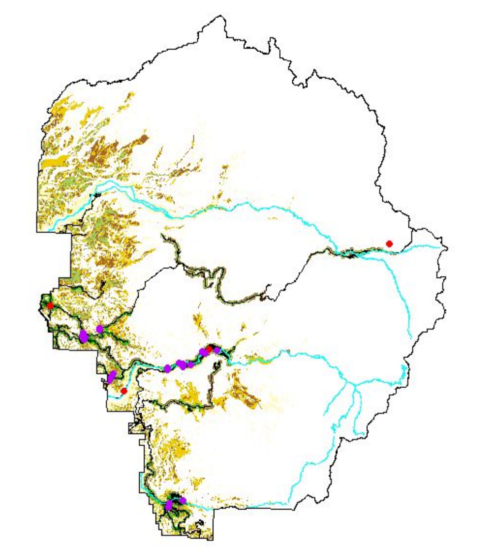


Figure 28

108

LEGEND

Probability of presence

Figure 26
- 0.1%
- 100%

Figure 27
- 0.1%
- 100%

Figure 28 Probability landscape value
- 0.01 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1
- 1 - 1.2
- 1.2 - 1.4
- 1.4 - 1.6
- 1.6 - 1.8
- 1.8 - 2

- Model input plot
- Model verification plot
- Major river
- Road
- Trail
- Yosemite National Park boundary

TNC98/99 Plots: Species Group 4

Potential Distribution Based on Environmental Layers

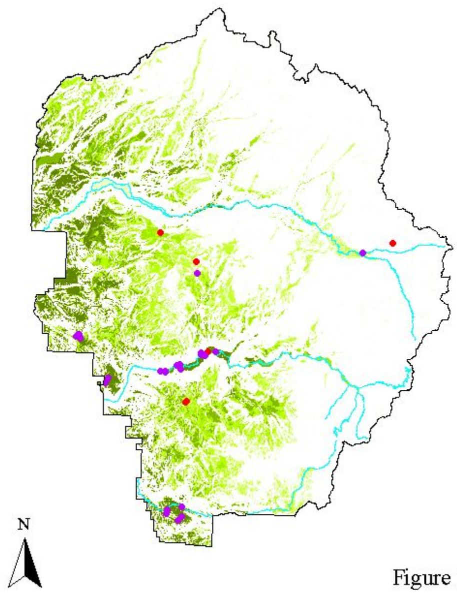


Figure 29

Potential Distribution Based on Anthropogenic Layers

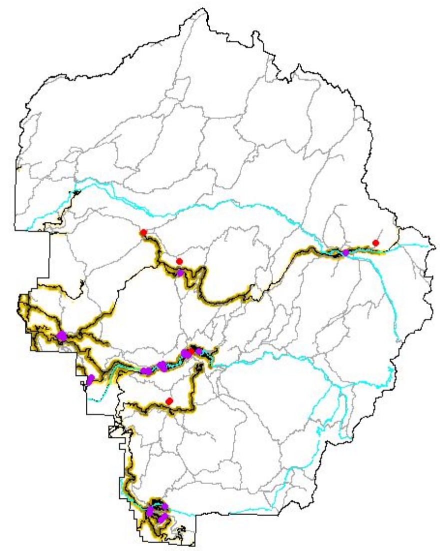


Figure 30

Combined Environmental & Anthropogenic Results

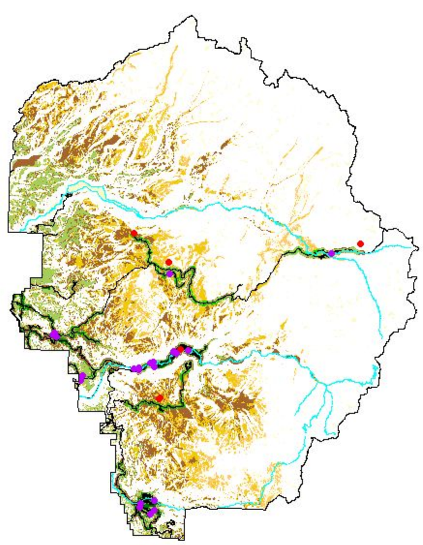


Figure 31

LEGEND

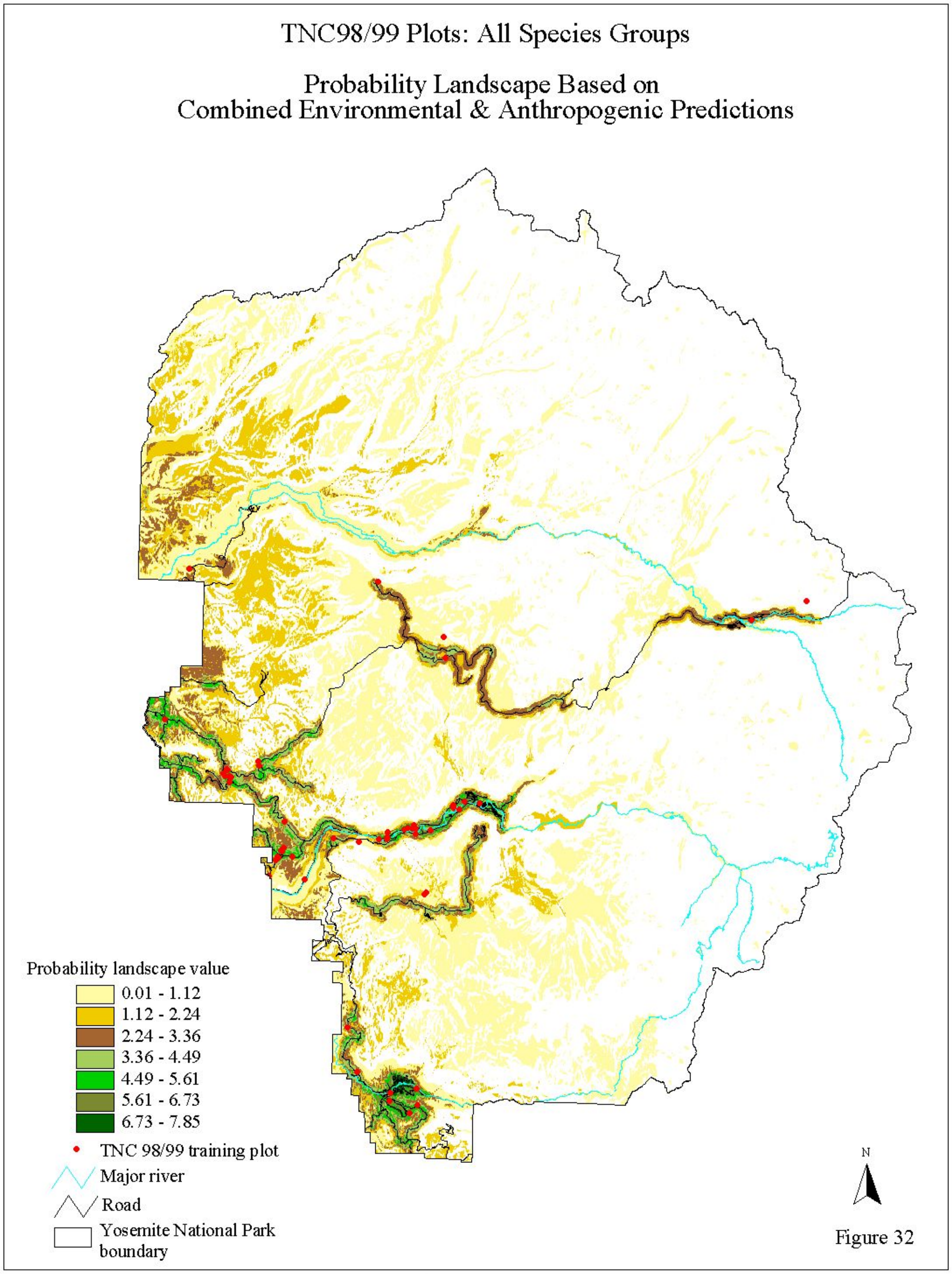
Probability of presence

Figure 29
- 0.1%
- 100%

Figure 30
- 0.1%
- 100%

Figure 31 Probability landscape value
- 0.01 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1
- 1 - 1.2
- 1.2 - 1.4
- 1.4 - 1.6
- 1.6 - 1.8
- 1.8 - 2

- Model input plot
- Model verification plot
- Major river
- Road
- Trail
- Yosemite National Park boundary


TNC98/99 Plots: All Species Groups
Probability Landscape Based on
Combined Environmental & Anthropogenic Predictions
Probability landscape value
0.01 - 1.12
1.12 - 2.24
2.24 - 3.36
3.36 - 4.49
4.49 - 5.61
5.61 - 6.73
6.73 - 7.85
TNC 98/99 training plot
Major river
Road
Yosemite National Park boundary
N
Figure 32
110

NRI/TNC Plots: Species Group 1

Potential Distribution Based on Environmental Layers

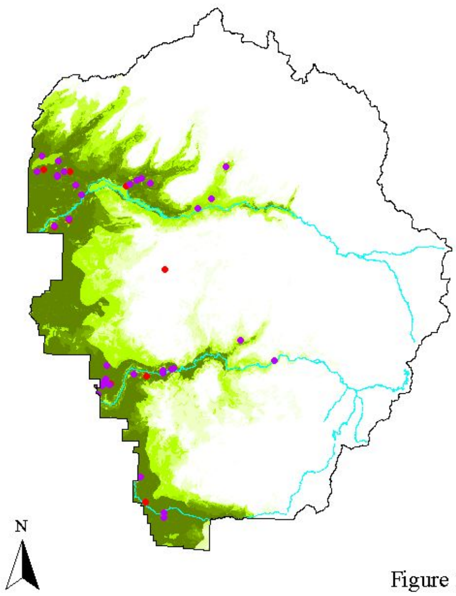


Figure 34

Potential Distribution Based on Anthropogenic Layers

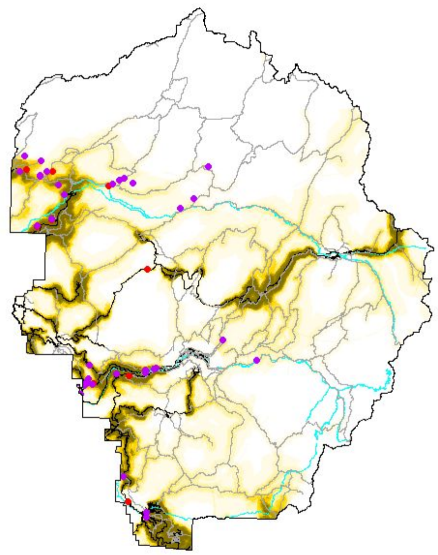


Figure 35

Combined Environmental & Anthropogenic Results

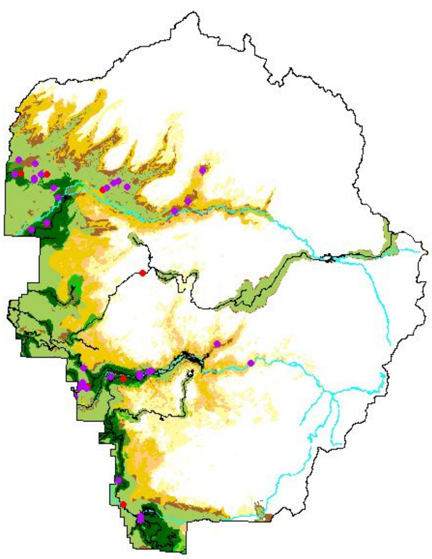


Figure 36

LEGEND

Probability of presence

Figure 34
- 0.1%
- 100%

Figure 35
- 0.1%
- 100%

Figure 36 Probability landscape value
- 0.01 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1
- 1 - 1.2
- 1.2 - 1.4
- 1.4 - 1.6
- 1.6 - 1.8
- 1.8 - 2

- Model input plot
- Model verification plot
- Major river
- Road
- Trail
- Yosemite National Park boundary

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NRI/TNC Plots: Species Group 2

Potential Distribution Based on Environmental Layers

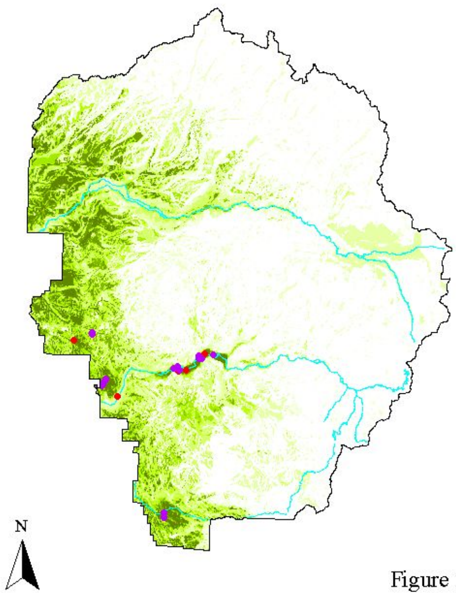


Figure 37

Potential Distribution Based on Anthropogenic Layers

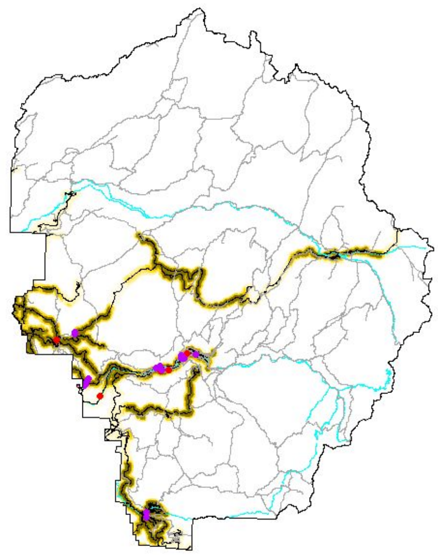


Figure 38

Combined Environmental & Anthropogenic Results

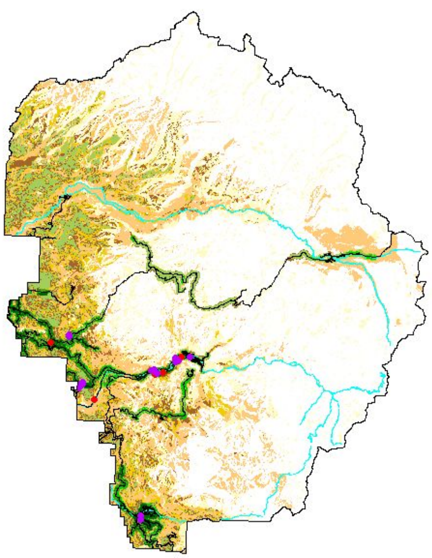


Figure 39

112

LEGEND

Probability of presence

Figure 37
- 0.1%
- 100%

Figure 38
- 0.1%
- 100%

Figure 39 Probability landscape value
- 0.01 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1
- 1 - 1.2
- 1.2 - 1.4
- 1.4 - 1.6
- 1.6 - 1.8
- 1.8 - 2

- Model input plot
- Model verification plot
- Major river
- Road
- Trail
- Yosemite National Park boundary

NRI/TNC Plots: Species Group 3

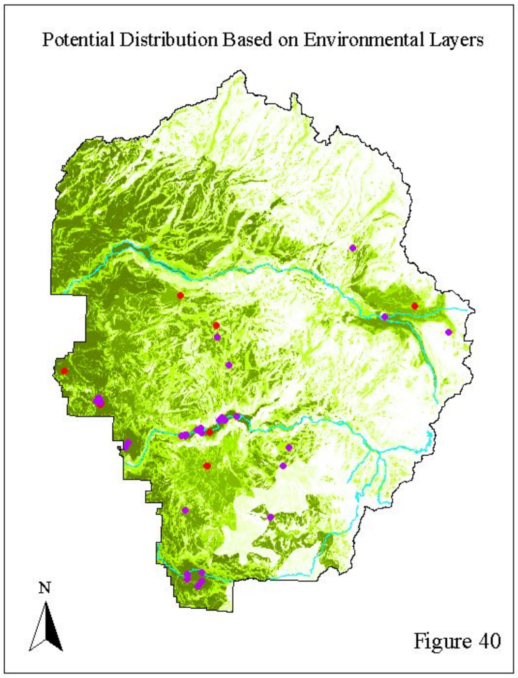


Figure 40

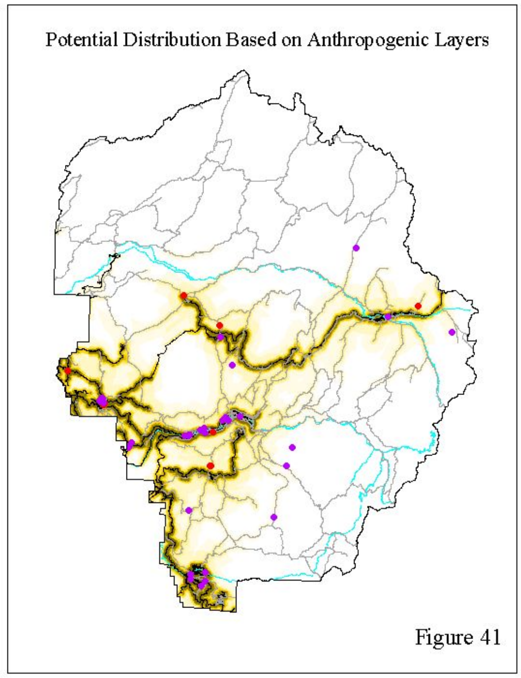


Figure 41

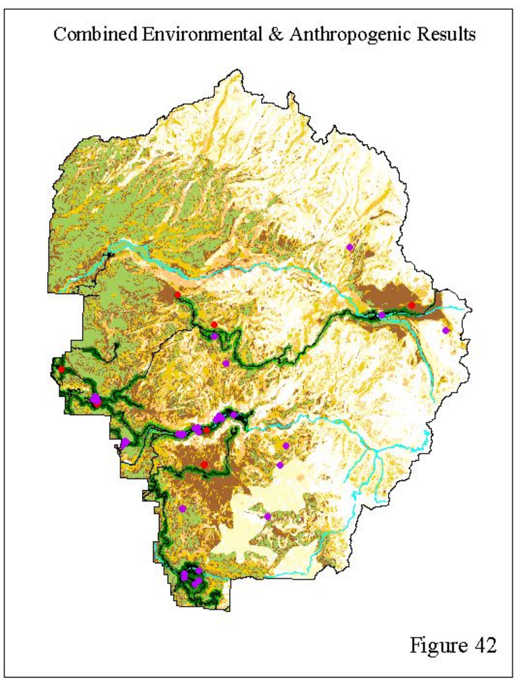


Figure 42

LEGEND

Probability of presence

Figure 40
- 0.1%
- 100%

Figure 41
- 0.1%
- 100%

Figure 42 Probability landscape value
- 0.01 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1
- 1 - 1.2
- 1.2 - 1.4
- 1.4 - 1.6
- 1.6 - 1.8
- 1.8 - 2

- Model input plot
- Model verification plot
- Major river
- Road
- Trail
- Yosemite National Park boundary

113

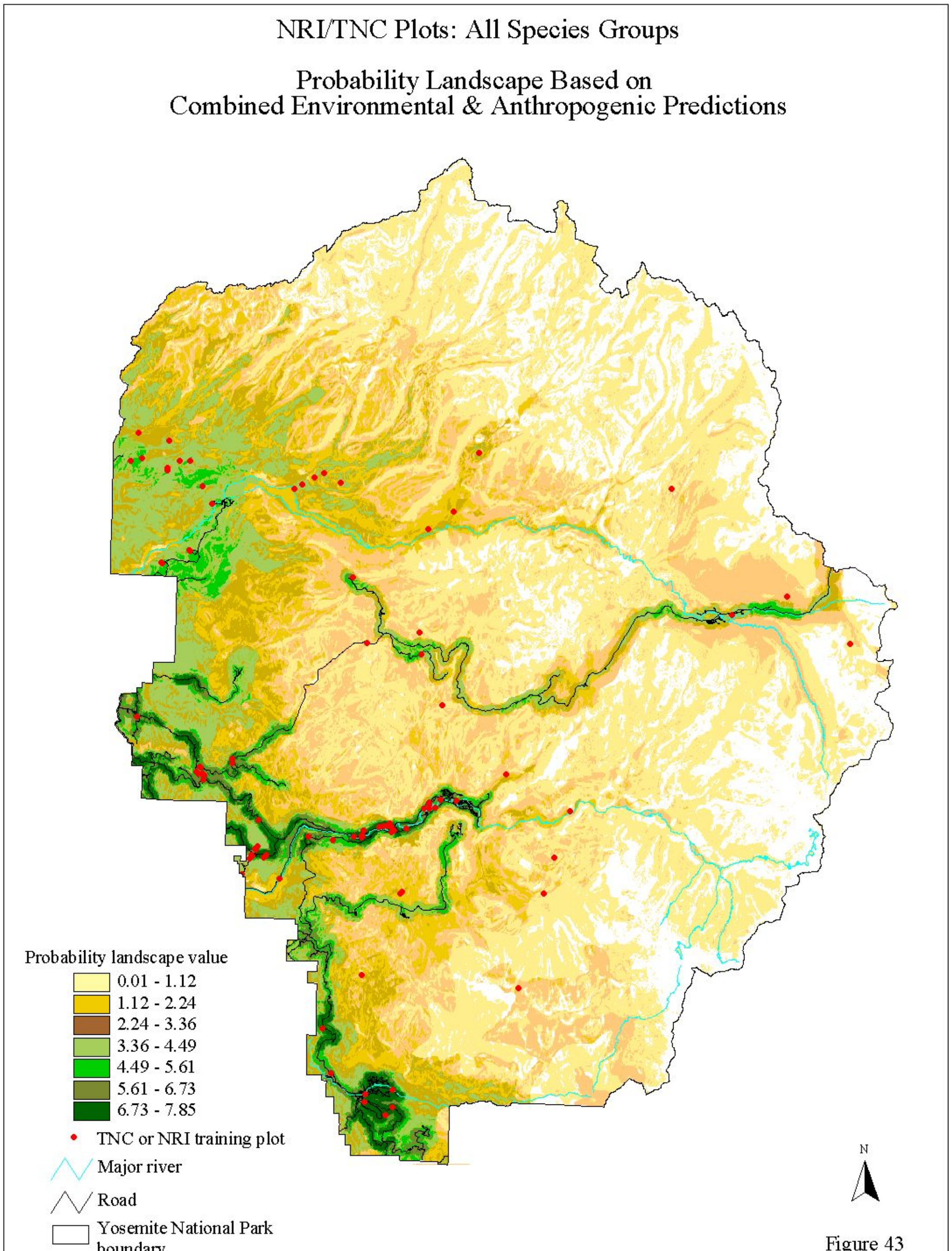
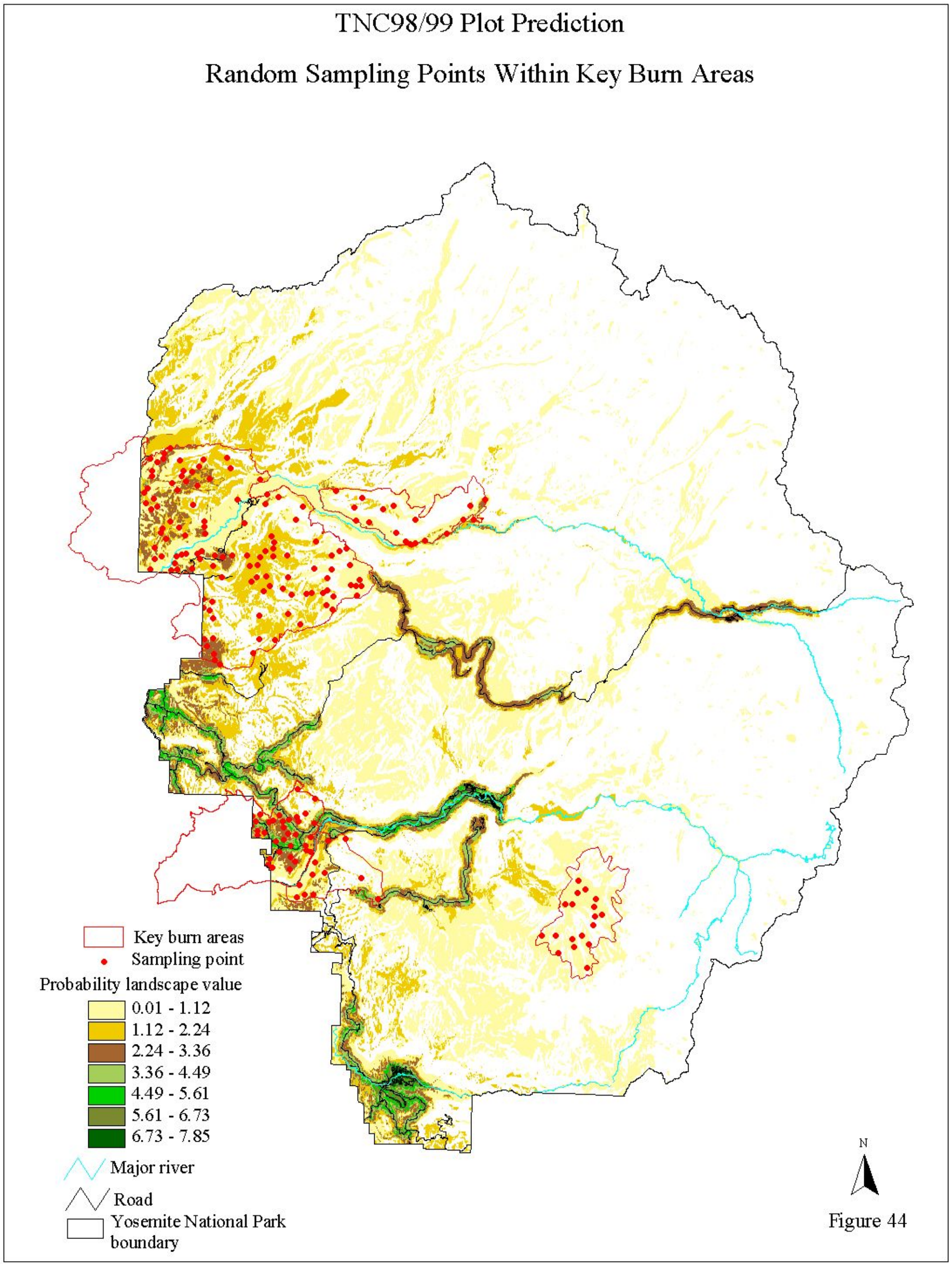


Figure 43

114


TNC98/99 Plot Prediction
Random Sampling Points Within Key Burn Areas
Key burn areas
Sampling point
Probability landscape value
0.01 - 1.12
1.12 - 2.24
2.24 - 3.36
3.36 - 4.49
4.49 - 5.61
5.61 - 6.73
6.73 - 7.85
Major river
Road
Yosemite National Park boundary
N
Figure 44

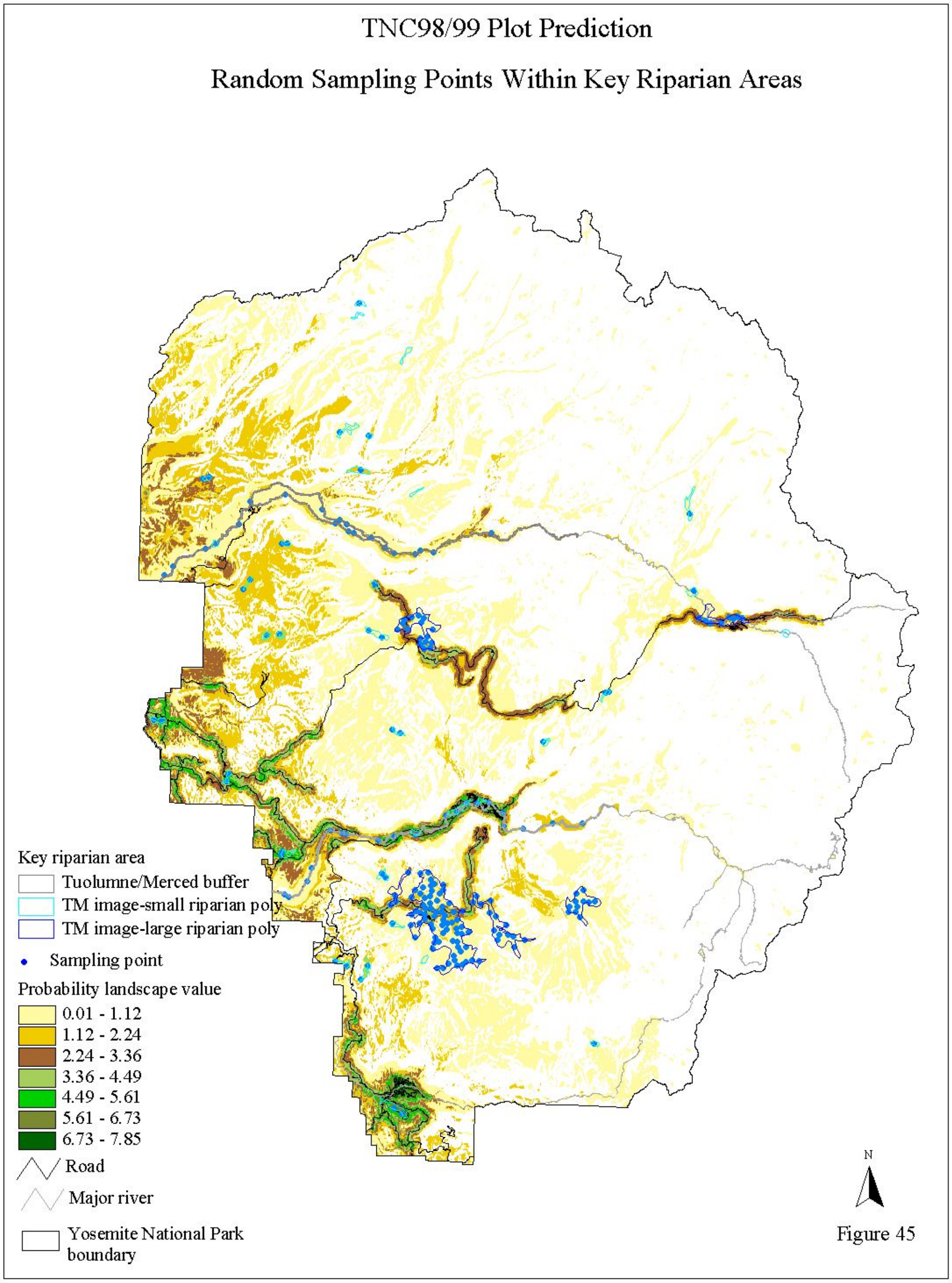


Figure 45

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SECTION VI: LITERATURE REVIEW

Fire & Invasive Species

Interest regarding the relationship between fire and invasive alien species is not a recent phenomenon. A small number of papers discussing this relationship appeared sporadically from the 1930's–1970's (Sampson 1944, Furbush 1953, Sharp et al. 1957, Harris 1967, Young and Evans 1971, Heady 1972). These were mainly review papers or observational studies of short duration (a period of a few weeks or months), and focused primarily on range degradation in grasslands and prairies of the central and western U.S. However, by the early 1990's the publication rate of studies on fire and invasive species had increased substantially, as had the geographic scope, method of study, and emphasis of research.

Prior to 1985, there was an average of one publication/7-8 years on fire and invasive species. Between 1985 and 1990 the rate increased to about 2 publications/year, but after 1990 the number of papers increased 8X, with a mean of 16 publications/year. However, this increase over the last 12 years has been exponential, with 59 papers on fire and invasive species published since 2000. Reviews by D'Antonio and Vitousek (1992), D'Antonio et al. (2000), and D'Antonio (2000) have analyzed global patterns of how invasive species have altered fire regimes (and other disturbance regimes as well). Regional patterns were reviewed in a series of papers from a workshop that focused specifically on the relationship between fire and invasive species (Galley and Wilson 2001). These regional reviews include Keeley (2001) for Mediterranean climate ecosystems in California (chaparral, Sierran mixed conifer forests, coastal scrub, etc.), Brooks and Pyke (2001) for deserts in the southwestern United States, Grace et al. (2001) for temperate grasslands in North America, Harrod and Reichard (2001) in boreal ecosystems of North America, and Mueller-Dombois (2001) for tropical ecosystems. Although they are narrower in geographic scope, these papers present a broader perspective than just alteration of fire regimes by invasive species.

The increase in publications on fire and invasive species over the last decade reflects the increased interest in invasive species in general. Invasive species are now considered one of the greatest threats to biodiversity and management of parks, reserves, and other natural lands (Drake et al. 1989, Simberloff et al. 1997, Mack et al. 2000). Many invasive species are known to exploit disturbed areas, whether the disturbance is natural (wildfire, flood, hurricane, etc.) or human-induced (road construction, prescribed burn, grazing management). Clearly, this has many implications for fire management activities. But while the implications are clear, solutions and suggestions are not. This is because there are several contradictory relationships between fire management and invasive species:

1. Invasive alien species can increase the frequency of fire, but in some instances they can also decrease fire frequency
2. Fire suppression leads to changes in ecosystem properties that, from a conservation perspective, are often undesirable. This includes alien species that can invade areas where fire is suppressed. However, fire suppression can also slow invasion.

3. Fire can promote invasion by alien species, but it can also be used to control them.

Much of the research on fire and invasive species in the last decade has focused on how invasive species alter fire regimes, as is reflected in the reviews by D'Antonio and Vitousek (1992), D'Antonio et al (2000), and D'Antonio (2000). Probably the most significant mechanism of alteration of fire regimes by invasive species is through the "grass-fire cycle". Invasive grass species become established in an area, often in areas where there has been a long history of fire suppression. This results in a continuous layer of highly combustible fuel and increased rates of ignition. Then, as a result of either shortened fire return intervals or fires that burn at greater intensity because of fuel buildup, areas that once were shrublands or forest are converted to grasslands. Where the forest and shrublands once had a high proportion of native species, the grasslands are comprised mainly of invasive species.

The grass-fire cycle has been reported in many parts of the world, including Hawaii, South Africa, Australia, and the western United States. In the western United States, the most notable examples are invasion of cheatgrass *Bromus tectorum* in the Great Basin (Whisenant 1990), *Bromus madritensis* ssp. *rubens* and *Schismus arabicus* in the Mojave desert (Brooks 1999), and *Lolium spp.* in chaparral and coastal scrub areas of southern California (Zedler et al. 1983, Haidinger and Keeley 1993). An important distinction between these three examples is that annual grasses were originally introduced into the Great Basin and Mojave Deserts through livestock grazing, military activities, or off-road vehicle use (Mack 1981), then spread throughout the ecosystem. *Lolium spp.* (and most other alien annual grasses) was also introduced into California through livestock grazing, but its effect on altered fire regimes is a result of it's being seeded into burned areas to reduce soil loss from heavy rains. The seeding program in conjunction with increased frequency of ignition in the heavily populated areas of southern California has prevented shrub recovery and led to type conversion from shrublands to grasslands [Haidinger, 1993 #44; Zedler, 1983 #50.

Examples of invasive species altering fire regimes by reducing fire frequency are far less common than examples of those that increase fire frequencies. An example from the United States is Chinese tallow *Triadica sebifera*. This tree has invaded extensive areas of coastal prairie and marsh in the southeast, forming dense thickets that suppress herbaceous species growth (Grace et al. 2001). The lowered levels of herbaceous cover results in reduced ignition in the stands.

Fire suppression has generally been associated with alteration of ecosystem properties that, from a management perspective, are undesirable. Fire is regarded as a critical process for many natural communities (Baker 1994, Biswell 1999). A number of studies have shown that long periods of fire exclusion contribute to significant changes in structural and functional components in many ecosystems (Parsons and Debenedetti 1979, Pyne 1984, Minnich et al. 1995, Mack et al. 2001). Fire exclusion also results in increased fuel loads, resulting in larger and more intense fires (Minnich et al. 2000). This leads to long-term changes in species composition within communities and dramatic changes in boundaries between communities. An increase in invasive species has also been documented in ecosystems that have had long periods of fire exclusion (Hobbs and Huenneke 1992, Bruce et al. 1995), while restoring natural fire regimes has reduced invasions in other ecosystems (Hermann 1993).

Fire restoration and fire suppression are both complicated by invasive alien species. Fire can lead to increased invasion by alien species in virtually any ecosystem (Brown and Minnich 1986, Bossard 1991, Busch and Smith 1995, Bell 1997, Crawford et al. 2001; see D'Antonio 2000 for a comprehensive review). This is especially true in anthropogenic landscapes that have been heavily disturbed (Bossard et al. 2000). But, alien species can also invade areas where suppression is the dominant management paradigm (Boyd 1995, Bell 1997, Gordon 1998, Huenneke *in press*).

The control of alien species with fire is a widespread practice (Randall 1996). The targets of burning are often individual species (Nuzzo 1991, DiTomaso et al. 1999, Klinger and Brenton 2000, Myers et al. 2001) but, in some cases, entire species assemblages (Parsons and Stohlgren 1989, Meyer and Schiffman 1999, Klinger and Messer 2001). Attempts to control species assemblages with fire have usually been focused on alien herbaceous species, especially annual grasses in the western U.S.

The success of fire as an agent of control of invasive alien species is mixed. In a recent review, D'Antonio (2000) reported results for 11 studies in North America and 8 studies in Australia that measured the response of invasive alien species to experimental burns. In the North American studies target species or guilds declined in 7 of the experiments, but in 2 of those experiments other alien species increased. In the other North American experiments there was either no change in abundance (n=2) or the target species increased (n=2). In the Australian studies there was no post-burn change in abundance of alien species in three of the experiments, alien species increased in three of the experiments, and abundance was reduced in the other two experiments.

The geographic scope of the relationship between fire and invasive species is nearly global (D'Antonio 2000). Countries where most research is being conducted include South Africa, Australia, and the United States. Regions with a Mediterranean or arid climate appear to be particularly susceptible to invasion. This may reflect the interaction of fire prone vegetation communities (the fynbos in South Africa, Australia's heath, grasslands and shrublands in the western U.S.), proximity of these communities to large cities, and invasive species that come from areas with a similar climate and so are "pre-adapted" to the ecosystem they are invading.

In North America invasive alien species have been reported to invade burn sites and/or alter fire regimes in almost all regions of the country (Whisenant 1989, Hogenbirk and Wein 1991, Nuzzo 1991, Bock and Bock 1992, Haidinger and Keeley 1993, Busch 1995, Myers et al. 2001). Ecosystems with particularly severe problems include Great Basin woodlands and shrublands (Whisenant 1989), the Mojave Desert (Brooks and Pyke 2001), Midwest grasslands (Grace et al. 2001), and California grasslands (Parsons and Stohlgren 1989, Pollak and Kan 1998, Klinger and Messer 2001).

Most research on fire and invasive species in California has focused on grassland ecosystems. Conversion of these grasslands from ecosystems dominated either by native forbs or perennial bunch grasses to ones dominated by alien annual grasses and forbs began over 200 years ago (Heady 1988). It has been suggested that fire could play an important role in restoring California grasslands to systems where perennial bunch grasses are again an important component of the flora (Menke 1992). Some studies indicate fire may be effective at controlling populations of some invasive alien species (DiTomaso et al. 1999), and that species richness and abundance of native forbs will increase temporarily after a burn (Parsons and Stohlgren 1989, Meyer and Schiffman 1999, Klinger and Messer 2001). Nevertheless, grasslands remain dominated by alien annual grasses after fire, and there have been no published studies indicating this pattern can be reversed (Parsons and Stohlgren 1989, Klinger and Messer 2001).

Not only does it appear that grasslands in California can not be restored to ecosystems with a significant component of native species, but they are also the ecosystems in the state that are most susceptible to new invasions by alien species (Bossard et al. 2000). Consequently, type conversion of shrublands to grasslands is a major concern (Keeley 2001). This is especially true in chaparral and coastal scrub areas of California. Intact shrub communities (i.e. where the horizontal and vertical arrangement of vegetation is relatively continuous) have very few alien species. These communities are considered to be "fire-adapted", with a fire return interval of 30-50 years (Biswell 1999). If fire return intervals remain within this range, then it is very difficult for invasive alien plants to become established *and persist* following a burn. Most alien species that invade burned areas are not shade-tolerant. As the canopy closes in, the aliens that have become established are shaded out.

The tendency of invading alien species to be excluded from burned shrublands can be altered by a decrease in fire return interval (Zedler et al. 1983, Whisenant 1989, Haidinger and Keeley 1993, Zedler 1995) or by swamping the species pool with propagules of aliens (Zedler et al. 1983, Beyers et al. 1998). Reducing the return interval results in high mortality for seedlings and saplings that have regenerated after the burn. Annual species are much more resilient to short fire return intervals than woody perennials. Therefore, reducing the fire return interval creates conditions annuals are able to persist in that woody species cannot. After any particular area of brush has experienced several burns within a few years of one another, what was once a shrubland will have been converted into grassland dominated by annual species. Alien annual species are better than native annuals at exploiting burned areas than native annuals, so grasslands converted from shrublands will be dominated by alien species. Since dried grasses are easily ignited, the fire return interval remains short enough that shrubs cannot re-colonize the site. Unless the fire return interval is lengthened through management action, the site will remain a grassland dominated by alien annual species (Minnich and Dezzani 1998).

Swamping the species pool with alien seeds can happen either through seeding burned areas (Beyers et al. 1998), proximity of a burned area to an unburned area that is dominated by invasive alien species (Zedler 1995, Turner et al. 1997, Allen 1998), and fire suppression activities (Giessow and Zedler 1996). Although seeding burn areas to reduce erosion has been shown to be of little benefit (Beyers et al. 1998), this practice is still widespread. The seeds are usually alien annual species, which by sheer numbers swamp native annual species. There appears to be a positive relationship between the distance of a burned area from areas infested with alien species and rates of invasion into the burn. This is important in areas fragmented by urban development, especially for smaller burns with a high edge/area ratio. Fire suppression activities (e.g. fuel break construction, heavy equipment and vehicle activity) can create disturbances that invasive species can exploit as well as introduce seeds from tools and other equipment.

There is a negative relationship between elevation and alien species richness (Schwartz et al. 1996, Randall et al. 1998, Keeley 2001). A mechanistic explanation for this relationship is not understood, but historical patterns of invasive species introduction to California and propagule pressure have been proposed (Rejmanek and Randall 1994, Schwartz et al. 1996, Randall et al. 1998). Surprisingly, ecological and biological factors correlated with elevation (vegetation community structure, reduced moisture, low temperatures, short growing seasons, etc.) have been alluded too but not stressed, although Rejmanek (1989) mentions in general that more extreme environments may be less susceptible to invasion. Nevertheless, as a consequence of this negative relationship, montane ecosystems in California (various conifer forests, mixed oak-conifer forest, montane shrubland) have low rates of invasion by alien plants However, there have been very few published studies on invasive species in these ecosystems (Randall and Rejmanek 1993, Bossard and Rejmanek 1994), and virtually no published data exists for their relationship with fire in these ecosystems (Crawford et al. 2001, Keeley 2001).

Fire suppression has led to a large proportion montane areas of that have not burned in a century or more (Skinner and Chang 1996). This is compared to median fire return intervals (prior to 1850) of 8–15 years in lower montane vegetation types and 11–70 years in upper montane types (Skinner and Chang 1996). Most fires in montane forests were probably low to moderate intensity and severity burns that consumed understory fuels but left the overstory intact; crown fires or stand replacement fires were likely an infrequent event (Skinner and Chang 1996). Because of the buildup of fuel over the last century, most fires are now high intensity, high severity stand-replacement ones. This shift in fire regime has important implications for invasive species management in montane areas. An intact overstory has been mentioned as being potentially important for reducing rates of invasion (Schwartz et al. 1996, Keeley 2001). Similar to the situation in shrublands, most invasive species in montane areas are shade-intolerant. Therefore, because a large proportion of the forest canopy is destroyed in high severity fires, it is possible that invasive alien species will increase in abundance over large areas (see Keeley 2001; page 84). As the number of burned areas increase across the landscape, these will act as source areas for alien species to invade from. It is important to note that the most common invasive alien species in burned areas in lower montane ecosystems of the Sierra Nevada is *Bromus tectorum*. *Bromus tectorum* has had drastic effects on fire regimes throughout the Great Basin (Mack 1981, Whisenant 1989), and there is concern that it could alter fire regimes in the Sierra Nevada as well (Keeley 2001).

In summary, the bulk of the literature on fire and invasive species is relatively recent (≤ 15 years). Mediterranean-climate ecosystems appear to be especially susceptible to invasion by alien species, and because they are also fire-prone much of the research on fire and invasive species is from these ecosystems (e.g. fynbos, heath, grassland, chaparral). Most of the recent emphasis has been on alteration of fire regimes by invasive species, but other important topics include: (1) the relative success of fire for controlling invasive alien species, and, (2) mechanisms leading to alien species invading and becoming established in burned areas. The scope of research on fire and invasive species has been very broad, and studies have been spread thinly across geographic areas, research questions, and taxa. Although patterns are emerging and speculation is rampant, there have been no formal hypotheses generated that could be modeled or experimentally tested. Consequently, generalizations and predictions are difficult to make in all but a few instances.

Riparian Communities & Invasive Species

Invasions of alien plants into riparian communities are a worldwide phenomenon (Loope et al. 1988, McIntyre et al. 1988, Thebaud and DeBussche 1991), but there have been relatively few papers published on the topic. Some studies have correlated patterns of alien species abundance with physical and biological properties of riparian systems (McIntyre et al. 1988, Roche and Roche 1991, Bruce et al. 1995, Bell 1997, PlantyTabacchi 1997, Stohlgren et al. 1998, Taylor et al. 1999, Choesin and Boerner 2000, Radford et al. 2001), but relatively few have focused on mechanisms driving invasion of alien species into riparian communities (Busch and Smith 1995, Burke and Grime 1996, Else 1996, Taylor et al. 1999, Sher et al. 2000). Most studies have been reviews, and have varied in scope from global (Elton 1958, Vitousek 1990, Hobbs and Huenneke 1992, Rejmanek 1999, D'Antonio et al. 2000, Huenneke *in press*) to regional patterns (Loope et al. 1988, Brock 1994, Dudley and Collins 1995, PlantyTabacchi 1997, Gordon 1998, Patten 1998, Rundel and Sturmer 1998, Glenn et al. 2001, Obedzinski et al. 2001). Other reviews have focused on particular species, especially the genus *Tamarix* and *Arundo donax* (Crins 1989, Brock 1994, Frandsen and Jackson 1994, Else 1996, Bell 1997), although other species-specific studies are not uncommon (Roche and Roche 1991, Thebaud and DeBussche 1991, Pysek and Prach 1993, Bruce et al. 1995, O'Connor et al. 2000, Radford et al. 2001).

In the United States, problems with alien species in riparian areas occur in most geographic regions (Roche and Roche 1991, Brock 1994, Bruce et al. 1995, Busch and Smith 1995, Dudley and Collins 1995, Bell 1997, Gordon 1998, Patten 1998, Stohlgren et al. 1998, Walters and Williams 1999, Glenn et al. 2001). Invasive alien plants alter flow regimes, sedimentation rates, community composition, and displace native species (Crins 1989, Vitousek 1990, Stromberg et al. 1991, Stohlgren et al. 1998). Woody invaders (e.g. *Tamarix* spp., *Melaleuca quinquenervia*, *Eucalyptus* spp.) are especially problematic in river corridors (Crins 1989, Gordon 1998, Rundel and Sturmer 1998), but herbaceous species can be problematic in swamps, ponds, and other areas where water does not flow swiftly (Roche and Roche 1991, Dudley and Collins 1995). An exception to this is

Arundo donax, which dominates river corridors in much of southern California and some other parts of the southwest (Frandsen and Jackson 1994, Else 1996, Bell 1997).

Although there is clearly a relationship between natural (e.g. floods, drought) or anthropogenic (grading, draining, channeling) disturbance and establishment of invasive plants in riparian areas (Hobbs and Huenneke 1992, Burke and Grime 1996, Else 1996, Taylor et al. 1999, D'Antonio et al. 2000), this relationship is not entirely straightforward. Although disturbance can create conditions that invasive alien species can exploit, in many instances it is alteration of the hydrologic regime that first enables the invading species to become established. Obviously, native riparian species are disturbance adapted. However, they are adapted to a particular disturbance and hydrologic regime. The majority of rivers in the United States (and much of the rest of the world) have had their hydrologic regimes altered. This has been done primarily through dams, channeling, bank stabilization, or other actions. This has generally led to reduced flows, increased sedimentation, lower water temperatures, and destruction of habitat, resulting in increased mortality and lower recruitment of native species (Stromberg et al. 1991, Busch and Smith 1995, Bell 1997, Patten 1998, Smith et al. 1998). Therefore, when alien species invade into these altered habitats, not only are they are able to exploit the physical conditions but there is reduced competition from native species. To compound this, some alien species can further transform the riparian conditions as a result of their own physiology (Bruce et al. 1995, Else 1996, Bell 1997, Sher et al. 2000).

Most studies on alien species in riparian areas of the United States have been conducted in arid and semi-arid ecosystems (Crins 1989, Stromberg et al. 1991, Brock 1994, Frandsen and Jackson 1994, Busch and Smith 1995, Bell 1997, Patten 1998, Smith et al. 1998, Obedzinski et al. 2001). Surprisingly, there have been no published studies of invasions into high elevation areas. This may have to do with the reduced rates of invasion into high elevation areas (see above section on *Fire and Invasive Species*), alien species not being pre-adapted to higher elevation conditions, relative lack of altered hyrdologic regimes at higher elevations, or a combination of the above. This does not mean alien species do not occur in riparian areas at higher elevations, but that their impacts have been negligible or relatively minor. Nevertheless, there is concern about populations of alien species becoming established in higher elevation riparian areas because of the potential for rapid expansion through these corridors (Schwartz et al. 1996, Stohlgren et al. 1998).

Consistent with this general pattern, invasions by alien species into riparian areas of the Sierra Nevada are happening primarily in lower elevation areas where there has been extensive alteration or loss of wildlands to urbanization and agricultural development (Schwartz et al. 1996). The southern and eastern side of the mountain range has some encroachment by *Tamarix* spp. and Russian olive (*Eleagnus angustifolia*) (Schwartz et al. 1996). Riparian areas on the western slope have localized infestations of Russian olive and tree-of-heaven (*Ailanthus altissima*)(Schwartz et al. 1996). A number of alien species that are highly invasive in riparian areas in other parts of California occur at lower elevations of Yosemite National Park (Gerlach et al. 2001). These species are primarily associated with areas of human activity (Gerlach et al. 2001), and none occurred in the data set we analyzed for this report.

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